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Vendace in the Bothnian bay

- Benchmark report 2021

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1. Contents

2. Excecutive summary

The data evaluation workshop was conducted 27-29th of October 2021, however some data related issues was not solved at the data meeting meaning that some work was performed intersessional in time for the benchmark that was held 7-10th of December 2021.

Both meetings was conducted online, and therefore the numbers of participants fluctuated through the meeting depending on the topic.

The report is structured into two parts. The first part reflects the data meeting and the decisions taken at that meeting event. The second part describes the benchmark meeting, which was more directed towards model runs and reference points. Here, decisions on model selection, on dimensions of the ensemble and choices of reference points are described in detail.

The major issues that was dealt with during this benchmark were:

- An ensemble model was used in order to incorporate the uncertainties regarding (*i*) productivity of the system, (*ii*) natural mortality and (*iii*) overall seal consumption
- New seal data was included, adding year 2019 and 2020 diet data. In addition, the uncertainties about the actual seal numbers and the proportion of the time the seals spend in the Bothnian bay was included as one dimension in the ensemble.

- A new management strategy evaluation approach, developed within ICES, for determining reference points was used in this benchmark.

- The other parameters associated to the assessment such as catch and landings data, tuning series and biological parameters (e.g., age-length-keys, maturity, and natural mortality) was scrutinized in the benchmark.

There are some outstanding issues for the next benchmark of this stock, the most important one being the stock identity. At the benchmark, a pilot study of the genetic structure of the vendace in the Bothnian bay was presented. Currently, results support the idea of demographic independence of vendace caught in Finland and in Sweden, albeit the difference was small. In addition, spawning vendace sampled in the Kalix river were genetically different from vendace sampled outside the river mouth and from the rest of the Swedish and Finnish samples, which suggests a more complex population structure of vendace than reflected in management. The difference in the genetics of vendace from within the Kalix river was more prominent then the difference between Finland and Sweden.There is, however, a need to expand the genetic pilot study, both spatially and temporally, to verify the stock structure of vendace and subsequently handle this accordingly in future management strategies.

3. Svensk sammanfattning

Förberedelser till Benchmarken startades tidigt under 2021 då en lista med saker som skall undersökas ytterligare innan data mötet skapades, en s.k. åtgärdslista

Den svenska sammanfattning kommer i stora delar att följa åtgärdslistan och fokusera på besluten som togs om vilka data som kom att användas i den slutliga beståndsanalysen.

Beståndsanalysmodell

Då det råder ganska stor osäkerhet i ett flertal olika modell-parametrar, har man under benchmarken använt sig av en ensemble-modell, vilket innebär att man kan köra flera modeller samtidigt. I varje modell kan man då använda sig av olika värden på de parametrar man är osäker på. Varje modell i ensemblen utvärderas sedan efter hur väl den klarar en serie statistiska test. Utifrån de statistiska testen så viktas respektive modells ”tyngd” i den slutliga bedömningen av beståndet.

Tabell 1. Olika konfigurationer av modellen som användes i ensemble-modellen, total 27 olika konfigurationer.

Parameter	**Nivåer**	**Totalt antal olika konfigurationer**
Säl predation	3	3
Naturlig mortalitet *(M1)*	3	9
Produktivitet	3	27

Beståndsstruktur

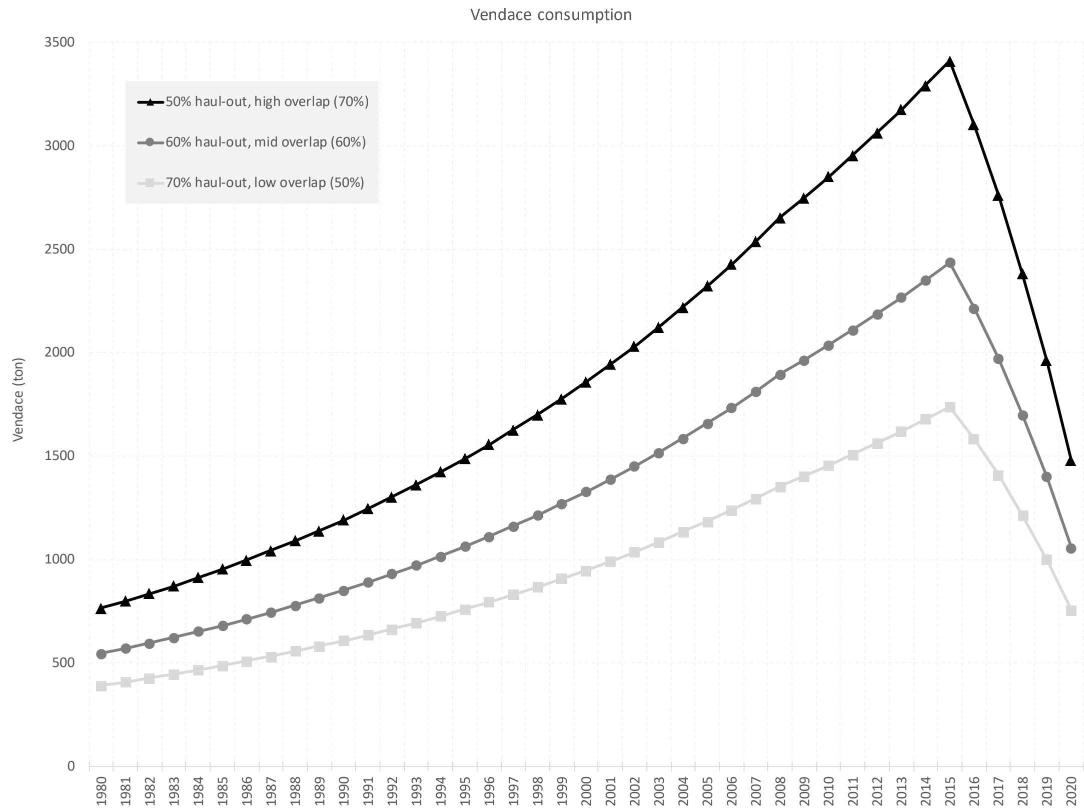
Under 2020 genomfördes en genetisk pilot studie som syftade till att studera om det finns ett eller flera siklöjebestånd i Bottenviken. Resultaten visar att det finns tecken på att det de svenska och finska bestånden är genetiskt olika, även om skillnaden är små. Resultaten visade även att lekmogna individer av siklöja provtagna i Kalix älv var genetiskt skilda från siklöja provtagna utanför älven och även från de övriga svenska och finska proverna. Skillnaden var större än skillnaden mellan Sverige och Finland, vilket antyder en mer komplex populationsstruktur av siklöja än vad som idag speglas i förvaltningen. De genetiska skillnaderna från projektet behöver dock verifieras med ytterligare prover som samlats in på fler platser och under olika tider på året, för att med säkerhet fastställa beståndsstrukturen hos siklöjan i Bottenviken, och sedan hantera detta på ett lämpligt sätt i framtida förvaltning.

Sälpredation

Det är i huvudsak tre faktorer som avgör hur stor del av siklöjebeståndet som äts upp av vikarsälar och som måste beräknas:

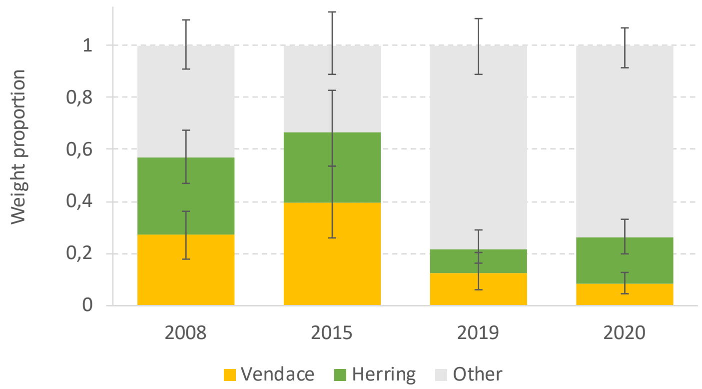
- Antalet sälar
- Hur stor del av året som sälarna befinner sig i Bottenviken
- Hur stor del av sälarnas diet som består av siklöja

Antalet sälar inventeras årligen under perioden på våren då vikarsälarna byter päls, där man antar att en viss del av populationen av sälar inte ligger på isen vid räkningstillfället. Man misstänker dock att proportionen av sälar som ligger på isen varierar mellan år, vilket ger en osäkerhet i uppskattningen av den totala mängden sälar på isen. För att inkludera osäkerheten i uppskattningen av sälar så användes 3 olika scenarier i beståndsanalysen; en låg, mellan och hög nivå (Fig. 1).



Figur 1. Tre olika nivåer av hur mycket siklöja som konsumeras av sälar. Nedgången under de sista åren beror av att siklöja inte konsumeras i samma omfattning som tidigare. Resultaten baseras på sälinventeringsdata och diet-prover.

För att beräkna hur stor del av året vikarsälarna befinner sig i Bottenviken användes resultat från en finländsk studie från 2011. I den studien märktes ett antal gråsälar med sändare med vilken man kunde se sälarnas position under studien.
Diet-data samlas in från skjutna sälar. Utifrån magprover så uppskattas andelen siklöja i magarna på sälen, där tidigare års diet data från 2008 och 2015 kompletterades med data från 2019 och 2020 (Fig. 2).



Figur 2. Vikt proportion av siklöja (Vendace) strömmig (Herring) och andra arter (Other) i dieten av vikarsäl under åren 2008, 2015, 2019 och 2020.

Fångst och landningsdata

Den nya beståndsanalysen har nu en tidsserie med landningsdata för åren 1963-2021. Ett stort arbete har lagts ner på att samla ihop och analysera landningsdata från olika källor tillbaka i tiden.

Fångst per ansträngning

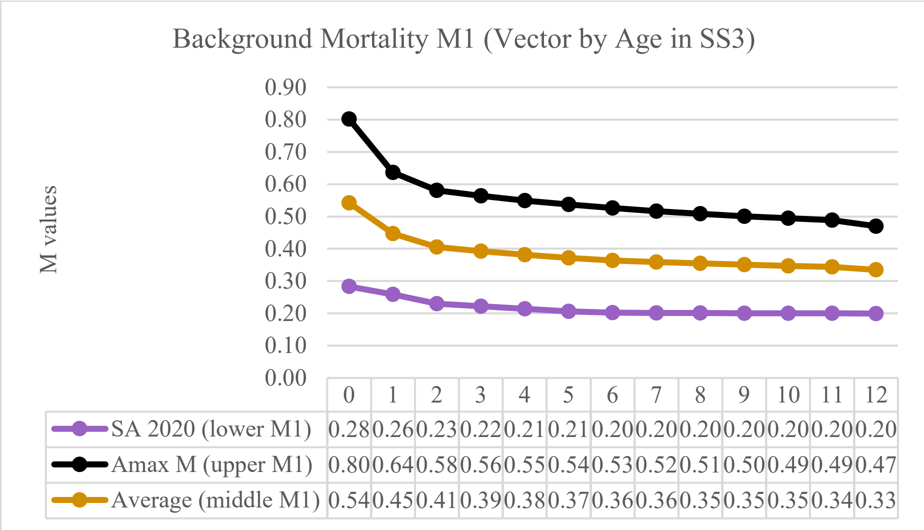
En tidsserie för fiskets fångster delat med antalet tråltimmar (kommersiell fångst per ansträngning) under åren 1999 till 2020 sattes samman och standardiserades inför data mötet. Under benchmarken beslutades det att även den skulle inkluderas i beståndsanalysen.

Trålundersökningar

En akustisk trålundersökning genomförs årligen under siklöjefisket. Denna trålundersökning genomlystes inför datamötet och olika metoder användes för att standardisera den.

Biologiska parametrar

De biologiska parametrar som används i en beståndsanalys har analyserats inför benchmarken. Dessa biologiska parametrar inkluderar ålder vid könsmognad, ålder vid längd, vikt per ålder etc. Inför benchmarken studerads den naturliga dödligheten (den dödlighet som inte beror på fiske eller sälar) extra noga, eftersom den naturliga dödligheten är en parameter som är väldigt svår att kvantifiera. I denna benchmark användes ett tillvägagångssätt där man använder sig av livshistorie-parametrar (livslängd, ålder vid könsmognad etc) för att uppskatta den naturliga dödligheten. I och med att vi använder oss av en modell som tillåter flera olika scenarier, så valdes 3 olika nivåer av naturlig mortalitet; låg, mellan och hög (Fig. 3).



Figur 3. Naturlig mortalitet. Tre olika nivåer av naturlig mortalitet användes i benchmarken, där varje nivå av den naturliga mortaliteten bygger på artspecifika livshistorie-data såsom maximal ålder, maximal längd, tillväxt.

Referenspunkter

Då man genomför en beståndsanalys jämför man beståndets nuvarande storlek och fiskeridödligheten mot beräknade referenspunkter. Om beståndet ligger över respektive under de fastlagda referensnivåerna så ökas respektive minskas kvoterna.

I denna benchmark så genomfördes en så kallad Management Strategy Evaluation (MSE) för att bestämma referensnivåerna för siklöjan i Bottniska viken, enligt resultat från de senaste expertarbetsgrupperna inom ICES, där olika internationella system för att hantera referensnivåer har jämförts. I MSE-analysen utforskades ett stort antal alternativ, där olika kombinationer av referensnivåer jämfördes och testades för att hitta de nivåer som ger störst långsiktig fångst samtidigt som att risken för att lekbiomassan går under 15% av den ofiskade lekbiomassan (B_0) är som högst 5%.

Resultatet av MSE-analysen visar att det fisketryck (F) som leder till en lekbiomassa som är 40% av B_0 ($B_{40\%}$) är den fiskenivå ($F_{B40\%}$) som ger störst långsiktigt säker fångst, där risken att SSB går under 15% av B_0 är lägre än 5%. Den lekbiomassa-nivå där F ska minskas ($B_{trigger}$) motsvarar då $F_{B40\%}$.

4. Description of the benchmark process

An issue list was set up early in 2021, covering the main areas where the data needed to be scrutinized. During 2021, a vendace task force was set up and several meetings was held in order to keep the work up to speed.

The data meeting was held by correspondence between the 27-29th of October 2021. During the data meeting, several decisions was made concerning the data input for the model. There was also several issues that was addressed during intersessional work before the benchmark.

The benchmark was also held by correspondence between 7-10th of December 2021. At the meeting the ensemble model was decided and the reference points for the stock was set.

5. Stock structure

Vendace in the Bothnian Bay (SD 31) is currently assessed and managed as two different populations: one population off the Swedish side of the Bothnian Bay and one population off the coast of Finland. This is despite the fact that the population structure of vendace in the Bothnian Bay is not well understood. Tagging studies conducted in the Luleå and Kalix archipelagos in the 1960s and 1970s show that vendace undertake natal homing, i.e. the adults return to their birthplace archipelago to reproduce (Enderlein 1977, 1986). Studies also show that vendace migrates eastwards in summer to feed in more nutritious waters, during which sub-populations/stocks from different fjords mixes (Enderlein 1986). Although the number of returns were few, some individuals were found to move all the way east to the Finnish coast (Enderlein 1986). Bergenius et al. (WD1) sampled vendace for genetic analyses in spawning grounds in the autumn 2019 and 2020 from the river mouths of Piteå and Kalix, and in the coastal areas off Piteå, Kalix and Luleå. Vendace were also sampled during the spawning season in 2020 from two locations off Uleåborg in Finland. The study showed that samples from the Kalix River clearly differed from the rest of the samples and that the second largest genetic difference was observed between Swedish and Finnish samples. The results need to be confirmed with more samples/loci however, especially from the Finnish side, in order to conclude if the differences are large enough to consider them different stocks or if vendace in the Bothnian Bay should in fact me managed as one stock. Moreover, for the appropriate management of any fish population, considerations of the proportion of each component in the fisheries catch from a mixture of sub-populations is equally important as the identification of the genetic differentiations between the components. Thus, to conclude, there is presently indications, but no sufficiently strong evidence, for the separation of vendace in the Bothnian Bay into several populations for separate assessment and management. Research into this question should be prioritized to ensure genetic diversity and sustainable fisheries management of this population.

6. Catch and landings

An overview of the commercial catches of vendace made available to the assessment is provided in Table 2. and described in more detail in WD1: Bohnian Bay Vendace: Catch statistics and associated sampling. Catches included are derived from the historical data base for the years 1914 – 1960, fiskenämnden data and official catch statistics from trawling from the Swedish Board of Fisheries (FiV) 1961 – 2002, and official trawl catch statistics from 2003-2020 from FiV/Swedish Agency for Marine and Water Management (SWAM), corrected for catches of other species using the self-sampling program (Fig. 4 and 5; Table 2.). Catches of vendace by other gear than trawl are estimated from data from fiskenämnden 1961 – 1993 and official catch statistics from 1994-2020 provided by FiV/SWAM. Trawl catches and catches with other gear were added to form one single series of total catch. Discarding in this fishery is assumed to be negligible, which means that the amounts of landed vendace is also assumed to represent the catch of vendace.

Table 2. Fishery dependent catch data from trawl available for the vendace benchmark in 2021.

Data type	Years	Source
Historical Data	1914-2013	SLU Aqua, described in Hentati-Sundberg 2017.
Official catch statistics including vendace by other gear than trawl (e.i. trawl, meaning both gear 311 and 314)	1961-2002 2003-2020	Fiskerinämnden data. Catches compiled by Thomas Hasselborg by the FiVs office for investigation (utredningskontoret) in Luleå available at SLU Aqua. From FIV/SWAM provided yearly to SLU Aqua (Focat files)
The fishery induced self-sampling program of catch per haul for position of fishing, catch amounts, effort, species composition and proportions of old vs young vendace.	2003-2020	Filled in log sheets have been sent yearly from the majority of the fishing boat pairs to the coastal laboratory (FiV, and later SLU Aqua). SLU Aqua has a full record of these files.

The official catch statistics can be acquired from SWAM. The historical data and data from the self-sampling are available at SLU Aqua.

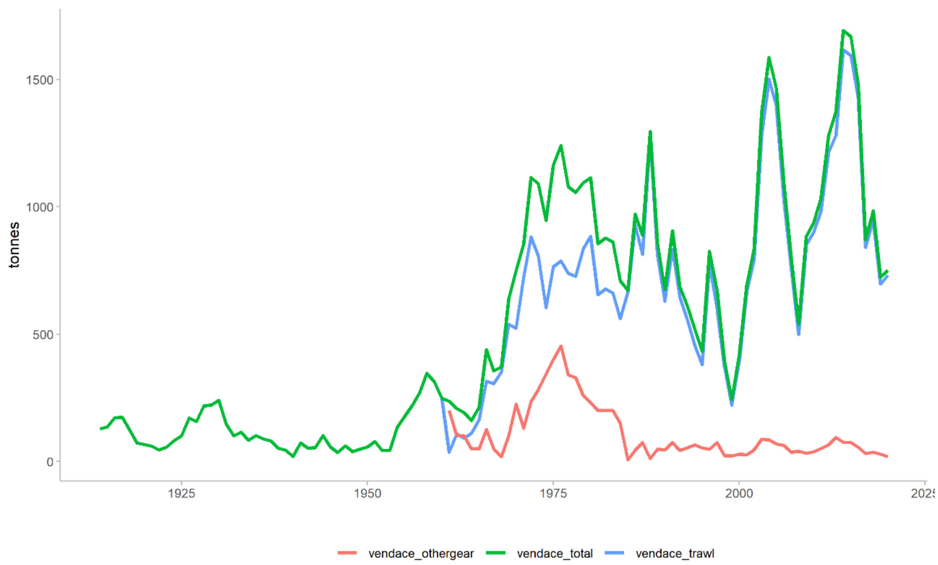


Figure 4. Vendace catch data for the new assessment. Vendace_othergear (red) show official catch statistics of vendace 1961 – 2020 and vendace_trawl (blue) show official catch statistics of vendace in trawls from fiskenämnden 1961-2002 and Fiv/Swam data 2003-2020 are multiplied by the proportions of vendace from the

self-sampling program. Vendace total (green) show historical catch 1914 – 1960 and vendace_othergear+ vendace_trawl from 1961 2020.

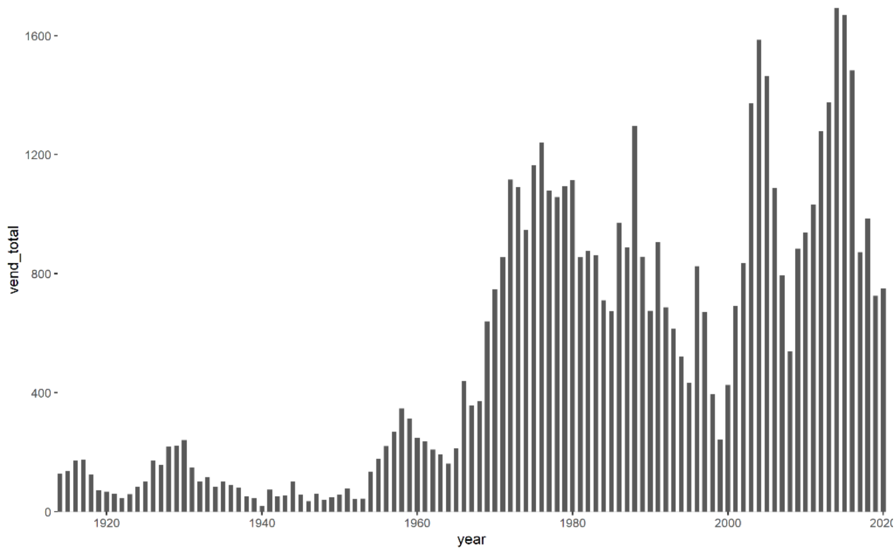


Figure 5. Vendace total catches proposed for the new vendace assessment model.

7. Discards

No discards have been reported for this stock. Discarding at sea is regarded to be negligible.

8. Tuning serie

An annual hydro-acoustic vendace survey, that cover the north-western part of Swedish exclusive economic zone (EEZ) in the Bothnian Bay, have been conducted since 2009.

In order to meet the survey objectives, the survey has been performed by using the mobile vertical acoustic-trawl survey method including the following components:

- systematic areal acoustic survey with zig-zag design transect to collect acoustic data covering the areas where the fish are,
- trawling to collect the biological data in order to determine the fish species composition and stock structure,
- environmental data collection for acoustic calculations and to explain distribution of fish which depends highly on salinity and temperature.

Further survey details are given in the vendace Stock Annex.

Based on the survey results two acoustic indices were presented for the vendace benchmark assessment: 1) survey index for vendace NASC, and 2) and survey index for vendace abundance at age in the study area (Tab. 3). The vendace NASC index represents the average vendace NASC and the acoustic vendace abundance index represents the number of vendace at age in the study area, i.e. the water area in the archipelago with an average depth <30 m, which is the environment that vendace prefers before spawning.

Table 3. Survey time-series: mean vendace NASC and abundance of vendace at age in the study area.

	NASC (vendace)	Vendace abundance (mln.)								
Year	($m^2/n.mi.^2$)	0	1	2	3	4	5	6	7	8+
2009	54	14	36	17	7	6	4	2	1	0
2010	94	9	62	35	13	8	5	2	1	1
2011	141	25	84	77	25	10	5	2	1	0
2012	106	14	90	37	18	6	1	2	1	0
2013	504	762	79	160	51	16	3	0	0	0
2014	166	60	168	42	24	5	2	0	0	0
2015	400	31	142	364	50	29	4	3	1	0
2016	309	85	153	133	161	4	2	0	0	0
2017	146	31	41	54	45	31	5	1	0	0
2018	183	78	62	46	28	21	23	4	1	0
2019	165	57	85	47	17	8	5	3	0	0
2020	114	25	67	39	11	4	3	1	1	0

9. Commercial CPUE

Two commercial catch per unit effort (CPUE) series were evaluated at the benchmark; one series based on the complete fishing fleet using the official catch statistics from the years 1999-2020, and a second series based on a reference fleet using data only from the self-sampling programme (Fig. 6, left panel). The reference fleet was constructed as a control series, because the full fleet series contained some misreports and disagreements between the official catch statistics and the self-sampling books. The reference series used data from four specific fishing boat pairs, selected because of their continuous fishing and reliable logging of data. These four boat pairs fished together for the entire time-period, and had a good match between their official catch statistics and self-sampling books. For this series, the year 2007 was set as a starting point, as this was the year when selective fishing gear was introduced across the fleet. No technical creep was accounted for in any of the series, as an interview among fishermen revealed that this was not an issue for the time-periods considered (WD4: Interview among vendace fishermen on technological improvements in the fishery). Annual CPUE values were calculated as the median of the total vendace catch in kg per trip divided by the total trawling hours for that trip.

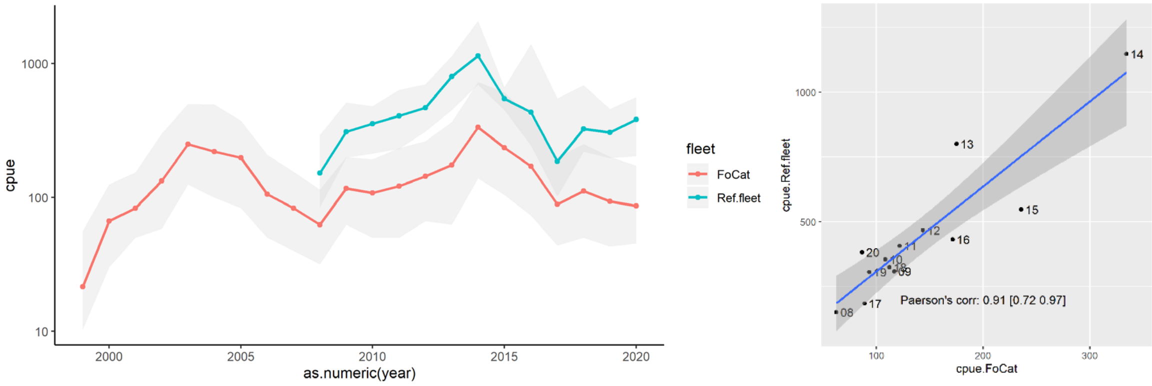


Figure 6: The complete fishing fleet and the reference fleet CPUE-series (left panel, red and blue series, respectively) and their Paerson's correlation (0.91, right panel). CPUE trend lines show yearly median values of vendace total catch [kg] per trip divided by total trawling hours per trip, with first and third quantiles (shaded bands).

As the CPUE-series (Fig. 6, left panel) Paerson's correlation was very high (0.91; 95% CI [0.72 0.97]; Fig. 6, right panel), it was decided to use the complete series as the CPUE data for the assessment.

10. Seals

The consumption of vendace, by year and quarter, by the ringed seal population in the Bothnian Bay was calculated from estimates of size and spatial distribution of the seal population together with proportion and length-frequency distribution of vendace in the seal diet. For more details, see WD 6.

Ringed seal population size and distribution

The ringed seal population size and distribution was estimated from monitoring data, telemetry data and information from literature. The ringed seal population is monitored by annual aerial line-transect surveys. The surveys cover a minimum of 13% of the entire ice covered sea area and the number of seals hauling out on the ice is calculated by extrapolating the survey strips to the entire ice-covered area (Härkönen and Heide-Jørgensen, 1990, Härkönen and Lunneryd, 1992, Härkönen et al., 1998) (Fig. 7). The ice conditions during 1988-2012 surveys are considered normal, whereas the more recent surveys have been characterized by anomalous ice conditions, believed to cause behavioural changes in the seal population and anomalous estimates on seal numbers. The estimated numbers of seals on the ice were calculated from a trend line based on the 'normal' condition period 1988-2012, and the numbers of seals on the ice during the anomalous period 2013-2020 were assumed to follow the same trend.

The proportion of the total population size being detectable on the ice is assumed to depend on the prevailing ice condition and behaviour of the seals, in combination with weather conditions and time of the day (Chambellant et al., 2012). No studies of haul-out fraction of Baltic ringed seals exist. The haul-out fraction during the moulting period was therefore assumed to range between 50% (upper level of the population size) and 70% (lower level), based on literature data (Fedoseev, 1971, Smith, 1973, Finley, 1979, Smith and Hammill, 1981, Kelly et al., 1986, Hammill and Smith, 1990, Stirling and Øritsland, 1995, Born et al., 2002, Bengtson et al., 2005, Carlens et al., 2006, Krafft et al., 2006, Kelly et al., 2010). The upper and lower population size levels for each year were calculated by dividing the trend-based estimated number of seals on the ice with 0.5 and 0.7, respectively (Fig. 7).

Ringed seals in the Gulf of Bothnia roam over large areas and are not limited to the Bothnian Bay (Oksanen et al., 2015). To estimate the proportion of time spent in the Bothnian Bay by the ringed seal population, thus overlapping spatially with the Bothnian Bay vendace stock, three levels of abundance of ringed seals in the Bothnian Bay were calculated, based on telemetry data (Oksanen et al., 2015) in combination with population size estimates (Fig. 7). The lower level assumed a haul-out fraction of 70% and a low (50%) overlap with vendace. The upper level assumed a haul-out fraction of 50% and a high (70%) overlap with vendace. The intermediate level assumed a haul-out fraction of 60% and mid (60%) overlap with vendace.

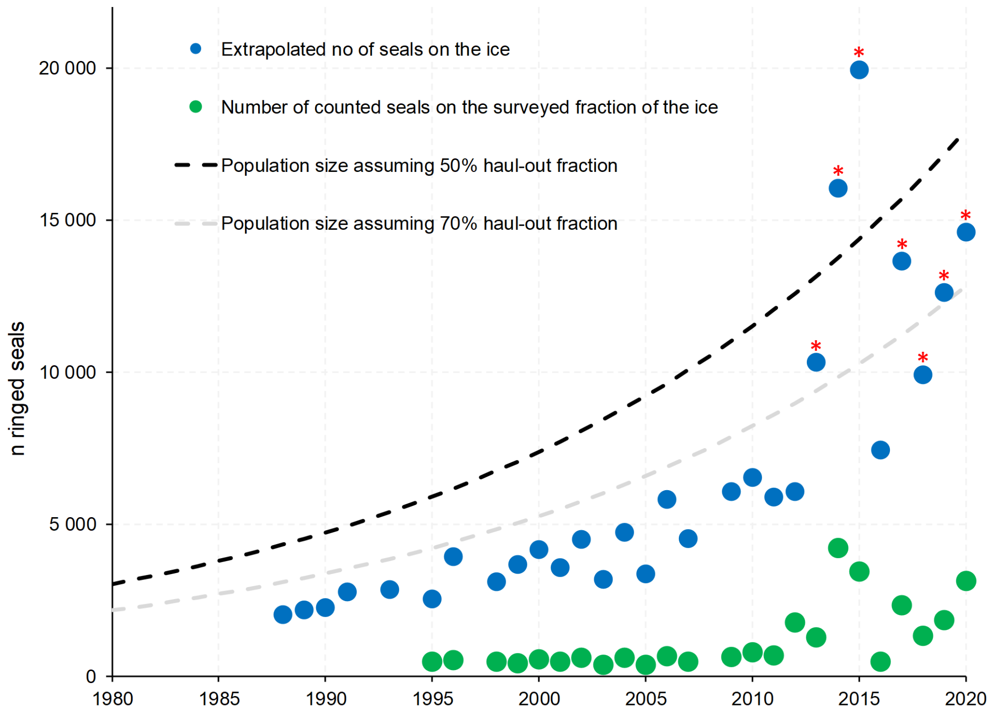


Figure 7. Number of ringed seals counted in the aerial line-transect surveys (green), extrapolated number of seals on the ice (blue) and estimated population size based on the population growth trend 1988-2012, assuming a haul out fraction of 70% (grey dotted line) and 50 % (black dotted line). The red asterisks define years with anomalous ice conditions and accompanying incomparably high estimates of seals on the ice, excluded from the trend-curve calculation.

Consumption of vendace by ringed seals in the Bothnian Bay

The prey choice of ringed seals in the Bothnian Bay was estimated from prey remains in stomachs and intestines collected from hunted seals. Otolith shape analyses in combination with machine learning techniques was used to discriminate between vendace and whitefish otoliths and account for mis-classification of otoliths from the *Coregonus* genus. The average proportions of otoliths assigned to vendace and whitefish were 78% and 22% in numbers, respectively, corresponding to 80% and 20% in weight.

Years from which at least 30 diet samples were available were chosen as reference years (2008, 2015, 2019 and 2020). The prey choice differed between the reference years (Fig. 8).

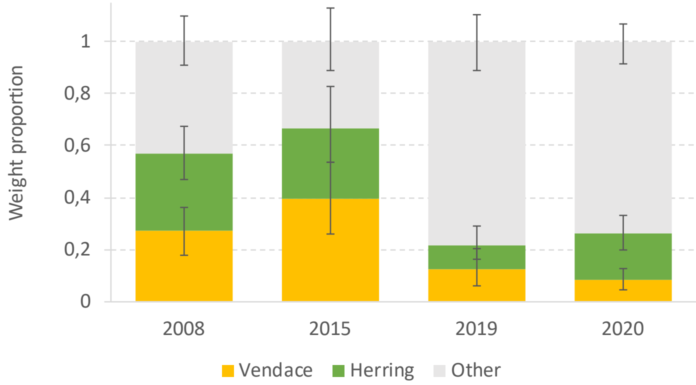


Figure 8. Weight proportion of vendace, herring and other prey species in the diet of ringed seals in the Bothnian Bay. Error bars indicate 95% confidence intervals.

The average weight proportion of vendace per quarter (Q) was calculated using otolith size-fish size regressions. The proportion of vendace in Q1 was assumed to be the same as in Q2; the proportion of vendace in Q3 was assumed to be the same as in Q4 (Table 4). The quarter-specific changes in vendace weight proportions between the reference years 2008-2015 and 2015-2019 were assumed to follow a linear increase or decrease depending on the data trend. The quarter-specific vendace weight proportions 1980-2007 were assumed to be equal to 2008, due to lack of data.

Table 4. Average quarter-specific (Q) weight proportions of vendace in the ringed seal diet in the reference years 2008, 2015, 2019 and 2020. Numbers within brackets show the number of samples.

Year	Q1-Q2	Q3-Q4
2008 (n=57)	0.23	0.59
2015 (n=34)	0.23	0.49
2019 (n=45)	0.02	0.33
2020 (n=103)	0.07	0.23

Using an energy consumption model, the individual prey consumption was estimated to 13 MJ$*$ day^{-1}, representing a prey biomass consumption of 2.4 kg$*$ day^{-1}. The year- and quarter-specific consumption of vendace by the ringed seal population in the Bothnian Bay was calculated by multiplying the weight proportions with the individual biomass consumption and the different levels of the population size (Fig. 9).

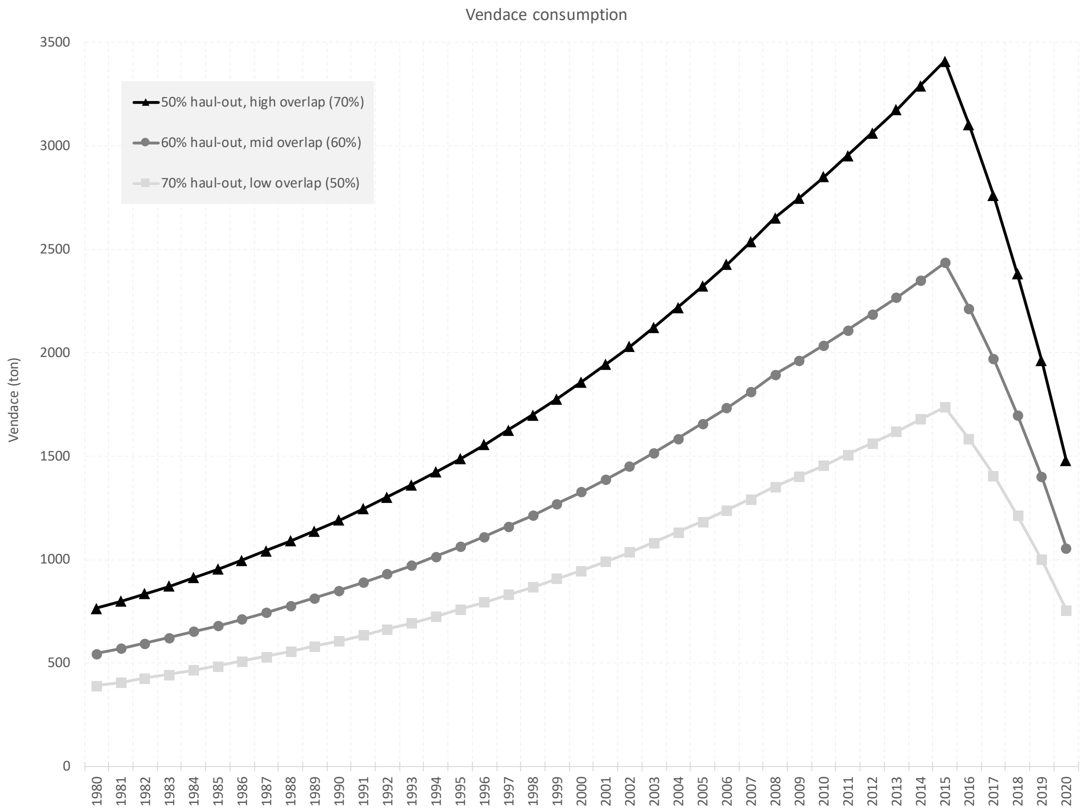


Figure 9. Annual consumption of vendace (ton) by the ringed seal population in the Bothnian Bay, estimated from different levels of size and spatial distribuition of the seal population.

The length frequency distribution of vendace in the seal samples from the reference years was estimated from size corrected otoliths (Fig. 10).

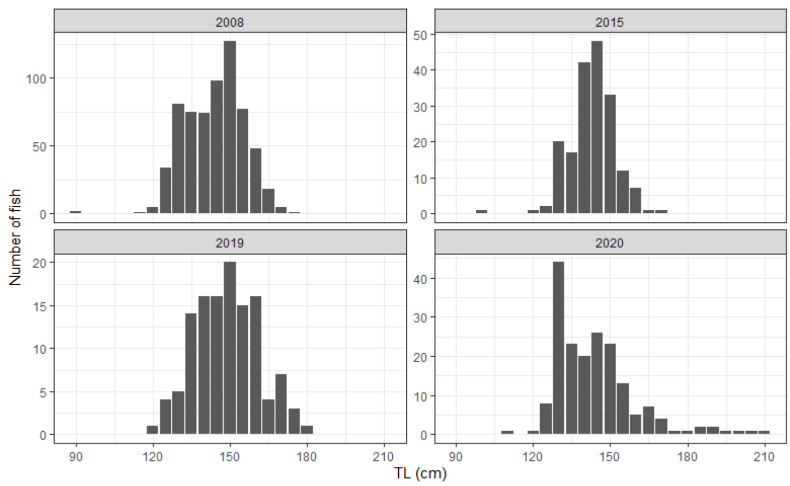


Figure 10. Vendace length frequencies distribution in the ringed seal diet in the reference years 2008, 2015, 2019 and 2020.

11. Natural mortality

Natural mortality is divided in two fractions, because of the seal predation, where the assessment model deals with these two types of sources of mortality separately. From now on, we refer to background mortality, (M1), as the non-seal mortality. Seal mortality (M2) is described in the Seals section of this report. For this benchmark assessment, a pool of methodologies were evaluated to assess the impact of M1 on the assessment.

Based on the assumption that Amax (maximum age) is the best information to be used, when available, for the final calculation of natural mortality (Then et al. 2015), the final derived M1 (Fig. 11) was calculated using the median of three methodologies described in Then et al. (2015) and Hamel (2015; in press). For the full details of the selection process of natural mortality calculation, see WD2, section Natural mortality.

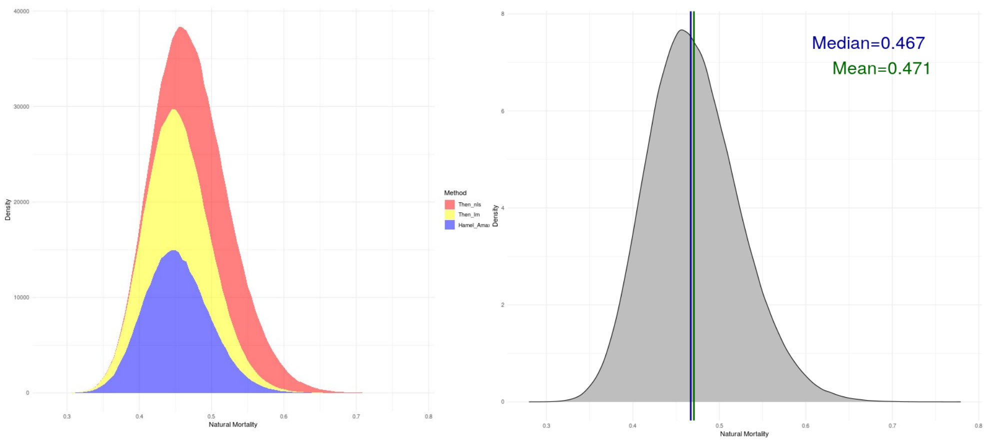
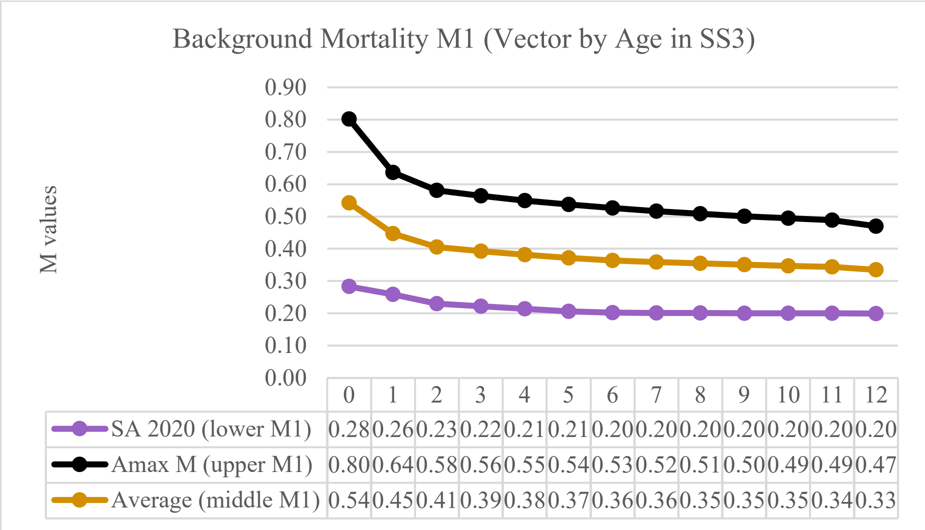


Figure 11. Estimates for the M1 from the three final methods separately (left) and the final composite M1 weighting the estimates together (right).

To represent structural uncertainty around background natural mortality, three plausible sets of M1's have been selected to be used in the assessment. Last year's assessment M is used as the lower limit for M1 and the composite M1 described above as the upper limit (values are taken as value at maximum age and scaled by the body size-at-age of the fish with Lorenzen option within SS3). In between, a middle value based on the average of the two vectors was decided to be added. The three M1s (Fig. 12) should be treated as alternative scenarios in the ensemble (M1 as one dimension of the ensemble grid).

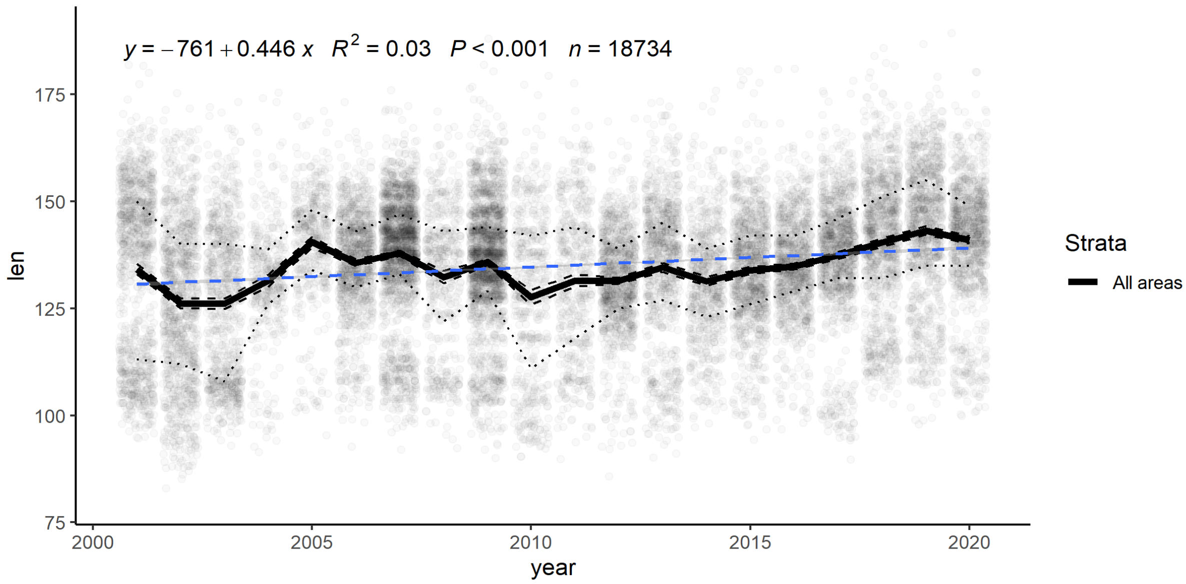


	0	1	2	3	4	5	6	7	8	9	10	11	12
SA 2020 (lower M1)	0.28	0.26	0.23	0.22	0.21	0.21	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Amax M (upper M1)	0.80	0.64	0.58	0.56	0.55	0.54	0.53	0.52	0.51	0.50	0.49	0.49	0.47
Average (middle M1)	0.54	0.45	0.41	0.39	0.38	0.37	0.36	0.36	0.35	0.35	0.35	0.34	0.33

Figure 12. The three natural mortality scenarios used in the assessment. Last year's assessment's M (grey line, 'SA 2020') is used as the lower limit, the composite M from this analyses (blue line, 'Amax M') as the upper limit, and the average (orange line, 'Average'). Values from the analysis are used for the M1 at maximum age. Younger age-classes' M1-values are scaled by the body size-at-age of the fish, using the Lorenzen option within SS3.

12. Mean length development

We found a general pattern of a small increase in mean length over time during the years 2000 to 2020 (Fig. 13) in the commercial data. For the full data set, including both northern and southern samples, vendace mean length increased, on average, by 0.4 mm per year (Fig. 13, upper panel). When separating the data into northern and southern areas, we note that the increase in length is larger in the north (0.6 mm/year) compared to the south (0.2 mm/year) (Fig. 13, lower panel).



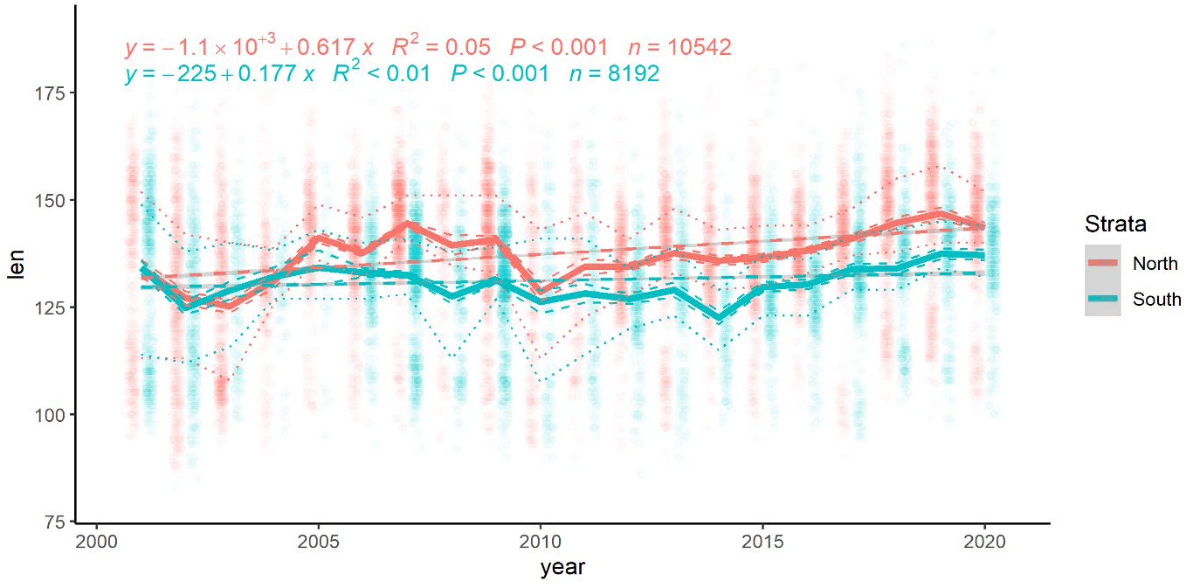
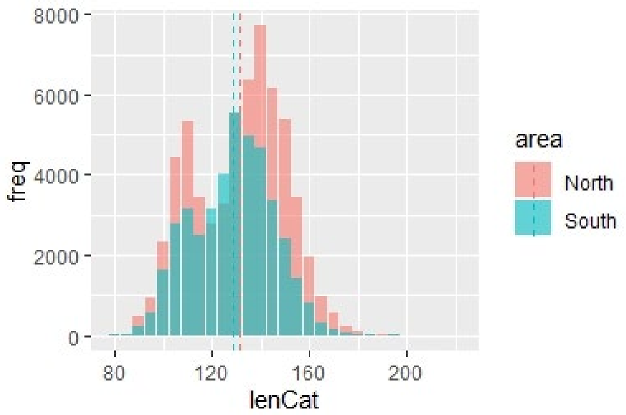


Figure 13. Mean (solid line) length over time, with +-95% CIs (dashed lines), and first and third quartiles (dotted lines), for all (upper panel) and northern (red, lower panel) and southern (blue, lower panel) areas, respectively. Straight dashed lines show the best fit OLS linear regression models, with +-95% confidence bands shaded in grey. Semi-transparent dots show the raw data.

13. Age Length Key and Length Frequency distributions

Length frequency distributions (LFDs) from the length-classified data show that fish from the northern areas are slightly larger than from the south (Fig. 14), whereas fish caught in September or October has approximately the same length (Fig. 15). See also Fig. 13 above for the general pattern of mean length over time.



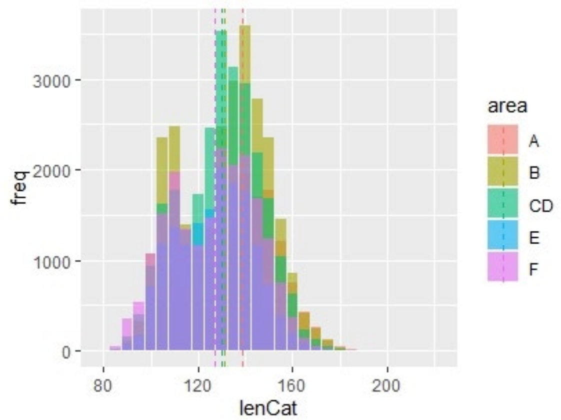


Figure 14. LFDs for years 1997-2020 from the length-classified data lumped together, stratified in to northern and southern (left panel) or areas A, B, CD, E and F (right panel). Dashed vertical lines show mean lengths weighted by number of individuals in each length class.

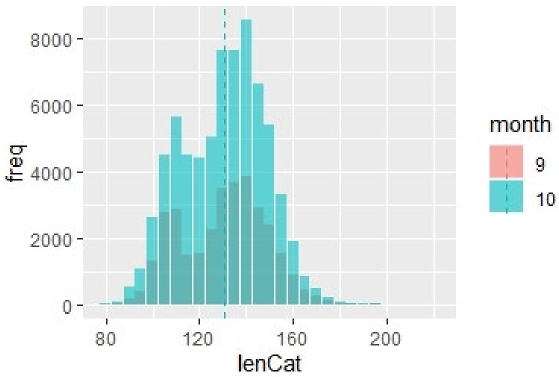


Figure 15. LFDs for years 1997-2020 from the length-classified data lumped together, stratified in to fish caught in September (9) or October (10). Dashed vertical lines show mean lengths weighted by number of individuals in each length class.

When separating LFDs across years, the length difference between areas is still visible, and a difference across months also becomes apparent for some years (WD2). Thus, we investigated the importance of the timing (month of the year) and the fishing area (A-F, North, South; WD2) of the fishing trips for estimation of age-length relationships and calculations of yearly fishery dependent and independent ALKs and LFDs. This was done by using a candidate model forward selection approach (e.g. Gerritsen et al 2006, ICES JMS) that evaluates the relative likelihood of a set of candidate models. The candidate model including fishing month of the year and area as explanatory variables was found to be the best model describing age as a function of length, for both commercial and survey data, although differences were not large. We do not consider the differences large enough to justify an area based assessment model, however a decision was taken that yearly ALKs and LFDs should be calculated taking fishing area (North/South) into account. For the full details of the candidate model analyses, see WD2 in this report.

Figure 16 illustrates the difference across the north and south areas in combination with fishing month, for the year 2020 ALKs. Again, we here see the difference in growth, especially for smaller (younger) fish, both for the commercial and survey data. For example, the conditional probability of age-1 fish, given a length of 135-145 mm, is larger in the north compared to the south, whereas for age-2 fish, given the same length, the relationship is the opposite (Fig. 16).

To account for the difference in growth across the north and south fishing areas when calculating yearly ALKs and LFDs, based on the commercial data, the number of individuals per length- and age-class was weighted by the proportion of total landings per area and year. As the survey data is collected along transects distributed evenly across the fishing areas, weighting by area when calculating ALKs and LFDs based on the survey data was not deemed necessary. Figure 17 and 18 illustrates the 'full' commercial ALK for the year 2020 and the LFDs for years 1997-2020, respectively, weighted by the proportion of yearly landings in the north and south areas.

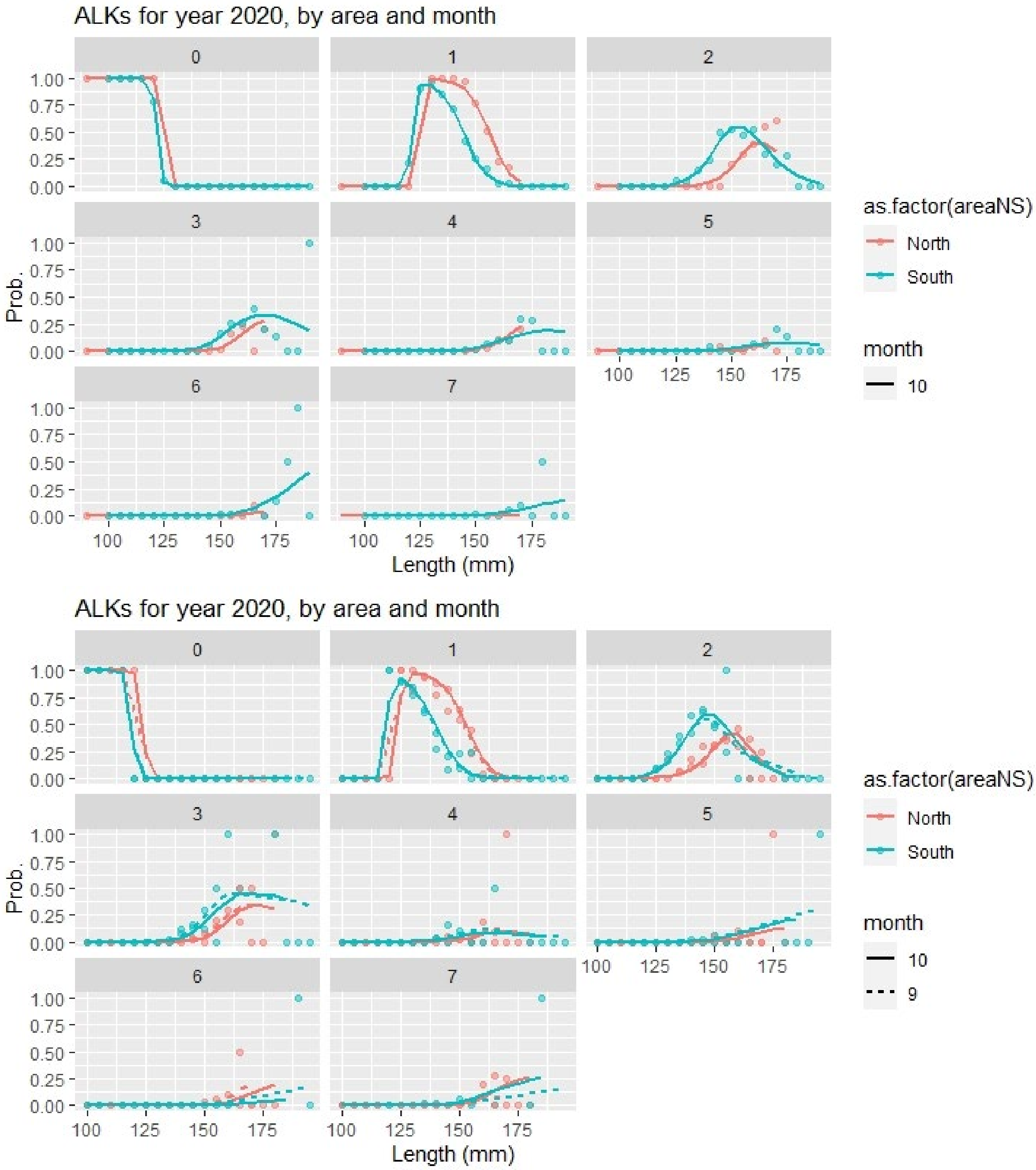


Figure 16. Age-length-keys for the year 2020, based on the commercial (lower panel) and survey (upper panel) data, by fishing area (North or South) and month (9 – Sep; 10 – Oct). Ages 0-7 are separated by panels. Lines show the best candidate model fitted to the data (dots). Note that the survey in 2020 was conducted in October, hence no data for September.

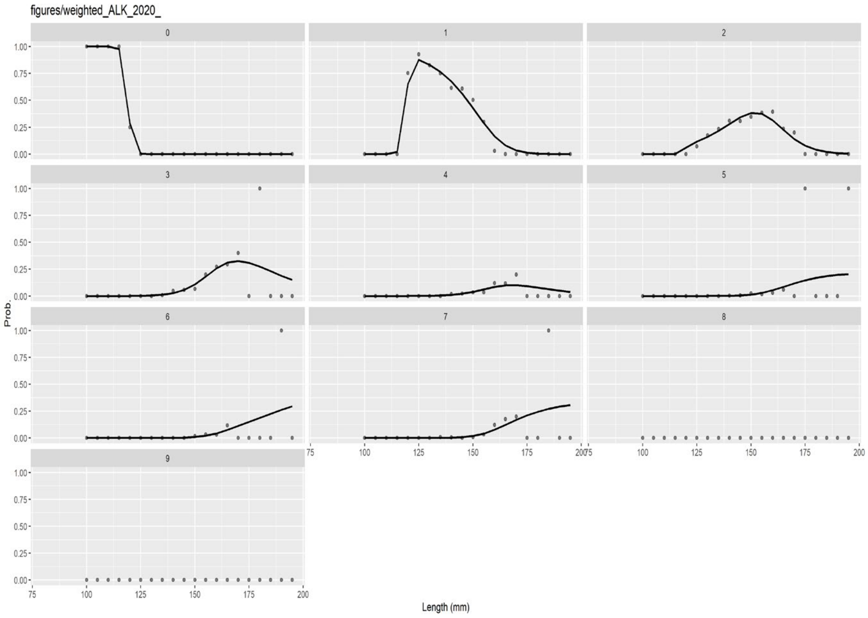


Figure 17. Age-length-key for the year 2020, based on the commercial data, weighted by the proportion landings by fishing area (North or South). Ages 0-9 are separated by panels. Lines show the best candidate model fitted to the data (dots).

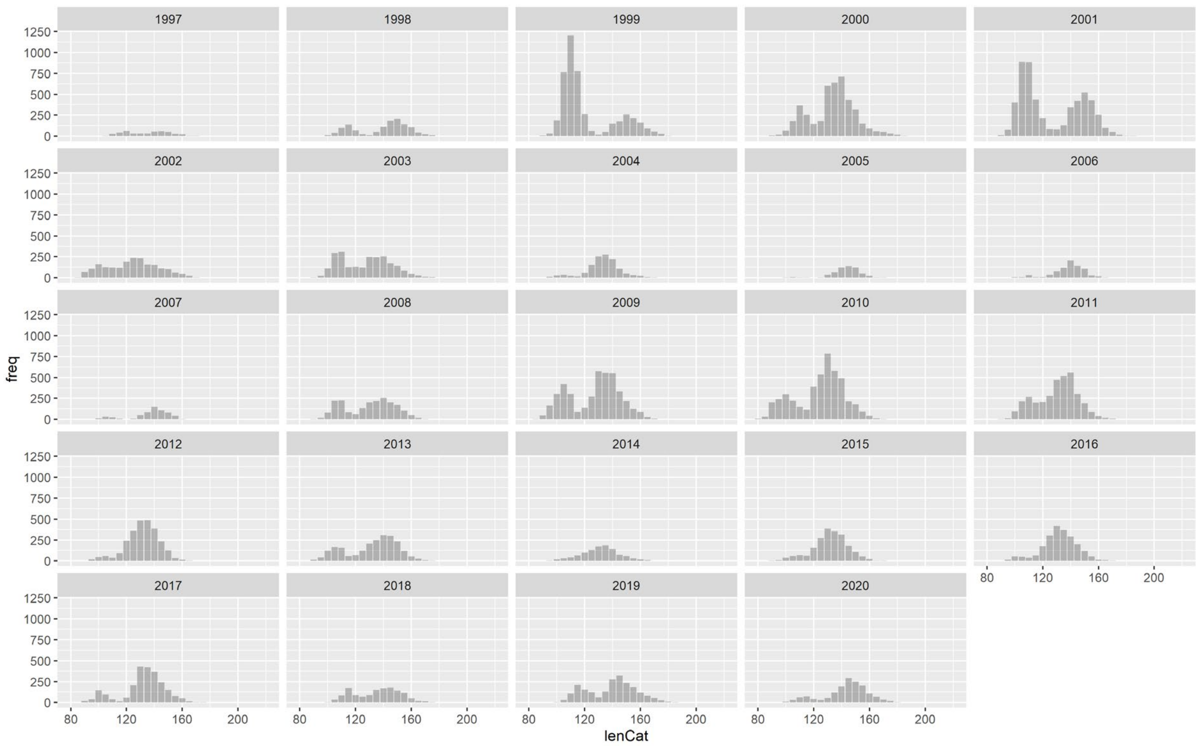


Figure 18. LFDs for years 1997-2020 from the length-classified, commercial, data, weighted by the proportion landings by fishing area (North or South).

14. Maturity

Length frequency and age distributions of data containing maturity stage information (WD2) reveal a better representation of the smaller individuals in the survey data. The survey data was therefore used for length and age based maturity ogive estimation.

All-years-combined L_{50} estimation using a binomial GLM reveals no major difference between sex (females 117 mm, males 113 mm). $L_{5}0$ for sexes combined (taking into consideration also immature individuals) is 119 mm (Fig. 19, upper panel). In conclusion, L_{50} can be set to 11-12 cm.

All-years-combined Age_{50} estimation using a binomial GLM reveals no important difference between sex (females 1 year, males 0.8 years). Age_{50} for sexes combined (taking into consideration also immature individuals) is 1.09 years (Fig. 19, lower panel). In conclusion, Age_{50} can be set close to one year.

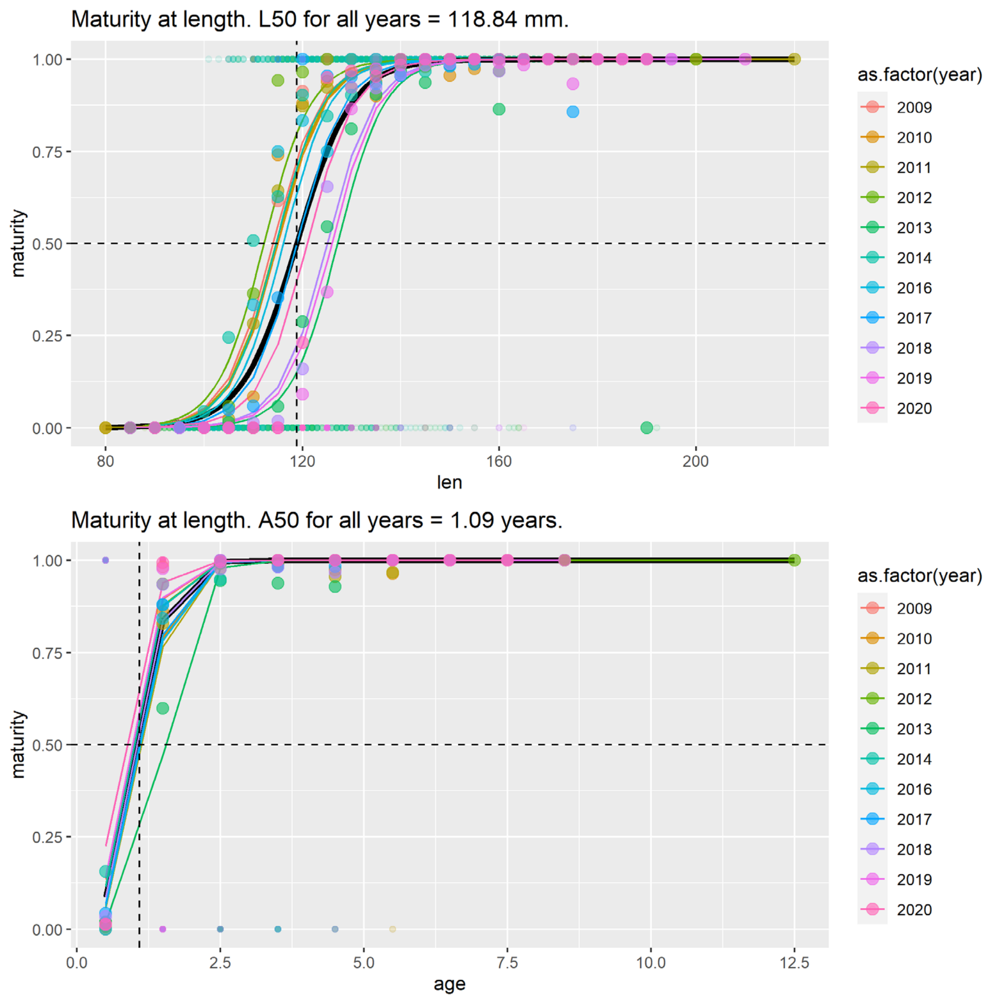


Figure 19. A binomial GLM model fit to survey female and male maturity ogive lengths (upper panel) and ages (lower panel), with yearly models and data (denoted by colour; small dots show the raw data, large dots show proportions per age/length-class) and the full model for all years (think black line). L_{50} and Age_{50} (dashed vertical lines) is estimated to the length and age were 50% of individuals are mature (dashed horizontal lines).

15. Weight at length

To calculate the weight-at-length relationships, the commercial and survey data was pooled and fitted to a power function (Fig. 20). Both yearly models and a combined model for all years were evaluated. The difference across years was not deemed large enough to motivate annual weight-at-length relationships.

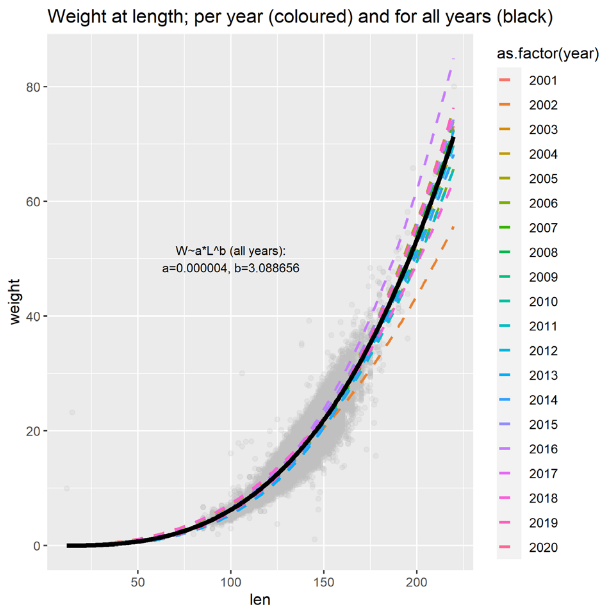


Figure 20. Weight-at-length relationships, fitted by year (coloured, dashed lines) and for all years combined (black, solid line) using the power function *weight ~ a * length^b*.

16. Growth

We found no patterns of sexual length dimorphism in the data (WD2). Length-at-age data revealed a difference in growth patterns across the northern and southern fishing areas, in line with what was found when calculating ALKs and LFDs. This was confirmed by a forward selection approach when evaluating the relative likelihood of candidate models which include or do not include area as an explanatory factor (see section *Length frequency distributions (LFDs) and Age-length-keys (ALKs)* above for details). Thus, the starting point for the growth analyses was based on combined sexes and data separated into the “north” and “south” fishing areas, using a Von-Bertalanffy (VB) growth model (Fig. 21).

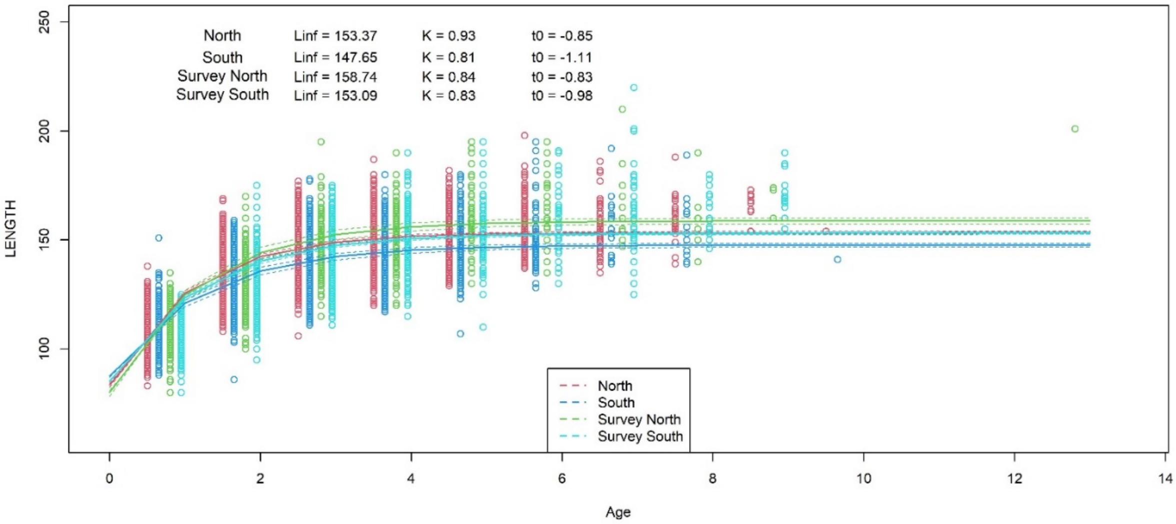


Figure 21. Von-Bertalanffy growth curves (solid lines) for the commercial (North, South) and survey (Survey North, Survey South) data, with 95% confidence bands (dashed lines).

We note that it is normal to observe statistically significant differences within sub-areas of the same stock (e.g. North-South). We do however not consider the difference found here in the VB growth curves to be large enough (Fig. 21) to justify an area based assessment model with the use of two different growth patterns.

We then considered a biphasic VB model, to correct for the absence of energetic costs linked to reproduction before sexual maturation (or the small energetic cost during the first few years after maturation) (Day and Taylor, 1997; Lester et al., 2004; Charnov, 2008; Quince et al., 2008a, b). The biphasic VB model (Fig. 22, upper), compared to the classic VB model (Fig. 22, lower), provided a better match of *Linf* (maximum length) in the model (182 mm [biphasic VB] vs 154 mm [classic VB]) and the *Lmax* data (~200 mm), and a residual analysis revealed a better fit to the data for the biphasic curve (WD2).

For the full details of the area based growth analyses and the classic vs biphasic VB analyses, see WD2 section *Von Bertalanffy growth parameters.*

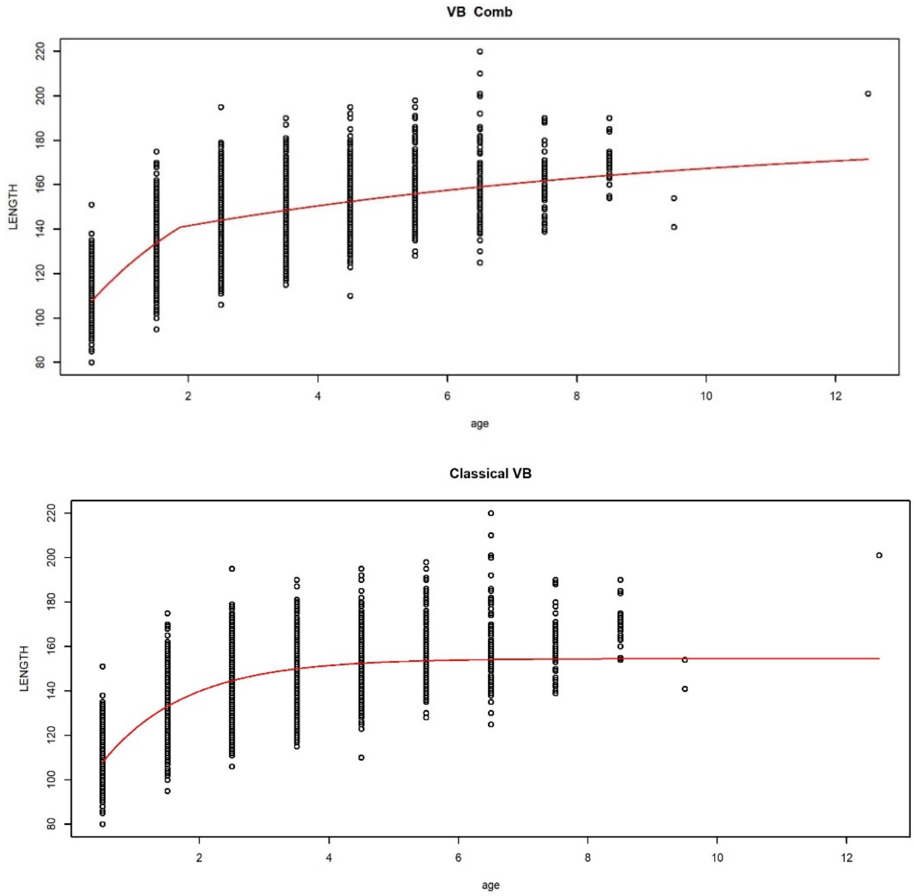


Figure 22. The biphasic (upper panel) and the classical (lower panel) VB growth models, respectively.

17. Assessment model

The ssessment of vendace in the Bothnian Bay was conducted using the Stock Synthesis (SS) model (Methot & Wetzel 2013, Methot et al., 2021). Stock Synthesis is programmed in the ADMB C++ software and searches for the set of parameter values that maximize the goodness-of-fit, then calculates the variance of these parameters using inverse Hessian and MCMC methods. The assessment was conducted using the 3.30.18 version of the Stock Synthesis software under the windows platform. A range of plausible scenarios (level of vendace consumption by seals, background mortality and steepness in stock-recruitment relationships; Tab. 5; WD 7: Ensemble model) was explored using an ensemble modelling approach, which better encapsulates the variability and uncertainty exploring contrasting but plausible ranges of parameter values over choosing a single set of fixed values (Dietterich, 2000; Tebaldi & Knutti, 2009).

The fitting of the model is satisfactory, with the aggregated length compositions well reconstructed (WD4: Stock assessment of vendace (Coregonus albula) in the Bothinan Bay (ICES SD 31)). The model generally shows good retrospective patterns and predictive skill, with diagnostic results (WD5) within the accepted limits used by the ICES framework for international stock assessment models. For full details of the evaluation, generality and robustness of the assessment model and the ensemble approach, see WD5 and WD7 in this report.

Table 5. Parameters and levels employed in the final ensemble assessment grid for vendace in Bothnian Bay.

Parameter	Levels	Pregressive number of runs	Values
Seals consumption	3	3	70% haul-out & low overlap (50%); 60% haul-out & mid overlap (60%); 50% haul-out & high overlap (70%);
Background mortality *(M1)*	3	9	Lower M1: 2020 Assessment; Medium M1: Average of Lower M1 & Upper M2; Upper M1: Estimated using t-max methods;
Steepness (*h*) in S-R	3	27	0.7;0.8;0.9

The assessment model of vendace in SD 31 is a one area, quarterly, length-based model where the population is comprised of 12+ age-classes (with age 12 representing a plus group) with sexes combined (male and females are modelled together). The model starts in 1965 (catch data prior to 1965 is used to anchor the model in the past) and the initial population age structure was assumed to be in an exploited state, so that the initial catches was assumed to be the average of preceding five years (1960-1964) in the time series. Fishing mortality was modelled using a fleet-specific method (Methot et al., 2021). Option 5 was selected for the F report basis; this option corresponds to the fishing mortality requested by the ICES framework (i.e. simple unweighted average of the F of the age classes chosen to represent the F_{bar} (age 1-3)).

Ringed seal predation is estimated by the model using time-series of vendace consumption by seals. The consumption of vendace by the ringed seal population in the Bothnian Bay is calculated from estimates of size and spatial distribution of the seal population, together with the proportion and length-frequency distributions of vendace in the seal diet (WD6: Ringed seals predation on vendace in the Bothnian Bay).

An overview of the data included in the final model is shown in Fig. 23 and described in detail in this report and in WD1 & 2.

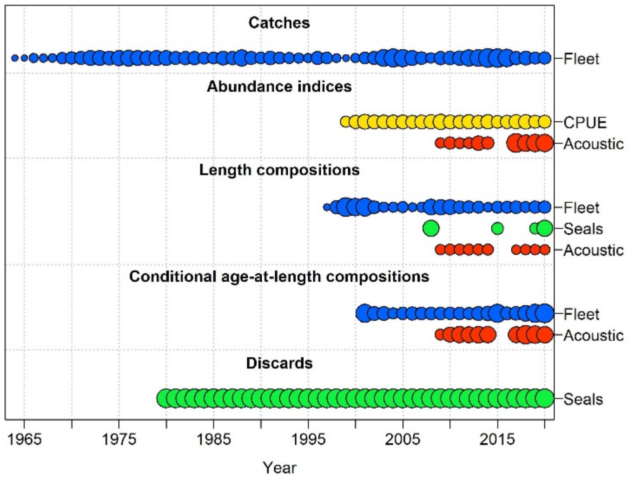


Figure 23. Vendace SD 31. Summary of the input time series included in the model.

18. Stock status

The ensemble model based on 27 model runs proposed during the benchmark (Table 5; WD7) has been considered as the final model for providing scientific advice. Figure 24 presents the main outputs from the final ensemble model compared with the single runs.

Total spawning biomass (Fig. 24, upper row) of vendace follows a fluctuating trend. In the last 20 years there have been two peaks (2005 and 2015) associated with favourable recruitment events occurring in previous years (lag of about 2 years between peak in recruitment and SSB). The last estimate of SSB in 2020 is 6964 tons (CI: 3711 - 14660).

Fishing mortality (Fig. 24, middle row) is defined as the average F of age classes 1 to 3. Historical F shows the great variability due to the relatively small amount of information (only total catches) for that part of the time series. From 1995 F stabilizes, always remaining at rather low levels. The last estimate of F in 2020 is 0.09 (CI: 0.04 - 0.16).

Recruitment (Fig. 24, bottom row) up to the year 2000 is quite constant as data informing recruitment estimates are only available since 1997 (first year of commercial LFDs). Since then, recruitment has shown a fluctuating trend with a high peak in 2013; in the last year estimated recruits are 300242 (CI: 96047 - 996929).

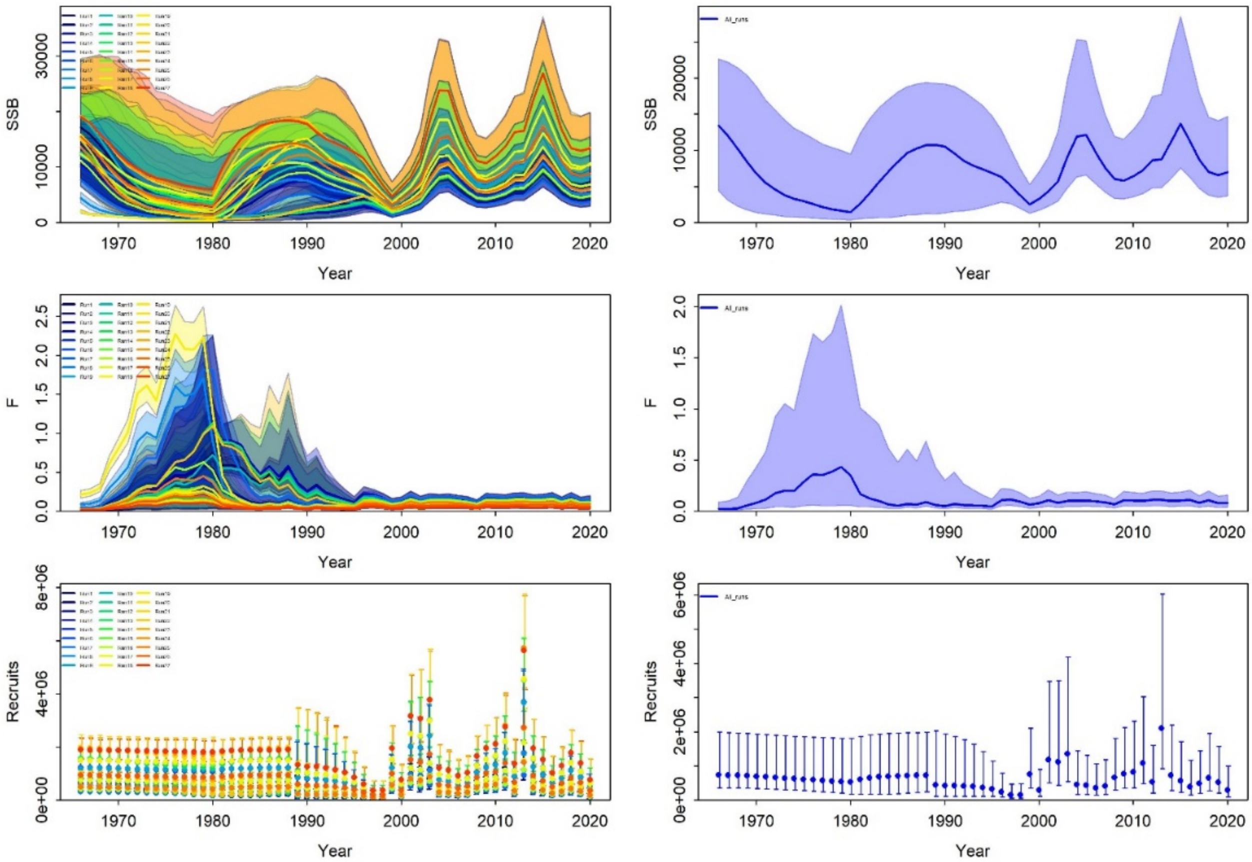


Figure 24: Comparison of stock assessment result between the 27 single runs (3 panels on the left) and the final ensemble model (3 panels on the right). Weighted-median value of SSB (tons), F and Recruitment with 95% confidence intervals from delta-MVLN (WD7).

Figure 25 shows the trajectory of the stock over the reference points (see section on Reference points below). In 2020, the stock is considered to be in a good status since spawning stock biomass is estimated to be above the reference point (SSB/SSBtrg = 1.55; CI: 1.00-2.11), and fishing mortality is estimated to be below the reference value (F/Ftrg = 0.18; CI: 0.07 - 0.42).

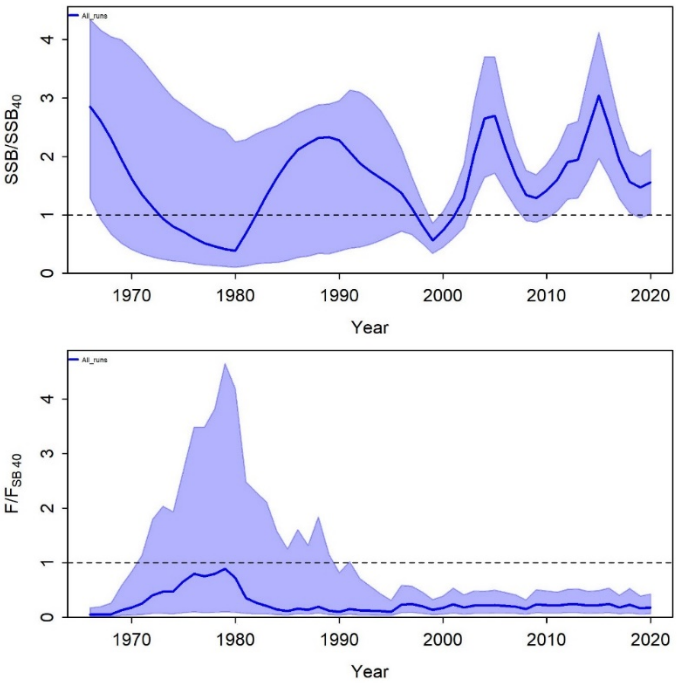


Figure 25. Stock status trajectories based on SS3 final ensemble model (weighted-median value of 27 runs). SSB/SSB_{40} (upper panel) and F/F_{40} (bottom panel) time series with 95% confidence intervals from MVLN.

19. Short term forecast

No short-term projections were made during the benchmark. For future vendace stock assessments, short-term projections should be made with Stock Synthesis using MCMC or the delta-Multivariate log-Normal' (delta-MVLN) estimator (Walter and Winker, 2019; Winker et al., 2019). MVLN infers within-model uncertainty from maximum likelihood estimates (MLEs), standard errors (SEs) and the correlation of the untransformed quantities and it has been demonstrated to be able to mimic the MCMC fairly closely. Moreover, the ensemble approach covering the three seal predation, three natural mortality and three stock-recruitment steepness scenarios (WD7) should be used for the forecast, where the final output from the ensemble model is based on the weighted median value of the 27 scenarios.

Using probabilistic forecasts, catch and SSB levels corresponding to different catch options are calculated as in typical deterministic short-term forecast but using MCMC to make it possible to also include the most correct associated probability of the SSB to be below biomass reference points, for each year of forecast. Therefore, an MCMC with 1 100 000 iterations, 100 000 burn-in and 1000 thinning should be run for the different levels of assumed F in the assessment year and assessment year+1, assuming F constraint in the intermediate year. It is important to note that the given F values for the forecast will sometimes be different from the model realized F in the MCMC (but also in the MLE if this is used for the forecast). This is because the F used is an average across ages, and those ages have different F, because they are affected by selectivity. Each draw of the MCMC has different selectivity so the F produced for each draw will be slightly different. We have tested running three different MCMC with 110 000 iterations and compared the difference in F inputted and model realized F.

A stock recruitment function with autocorrelation (Beverton and Holt) should be use for the forecast. Length-at-maturity, growth (length-at-age) and weight-at-length parameters are fixed, based on the analyses performed in this benchmark. Selectivity is constant. The amount of vendace caught by the seals during the forecast period should be set to the arithmetic average of the last 5 years for which seal predation data is available.

20. Reference points

The reference points were set following analyses recently conducted at the ICES workship WKREF1 (ICES 2021) (WD 8). The WKREF1 analysis compared the current ICES system to derive reference points (which has been used in the past for deriving reference points for vendace) against a set of alternative candidates based on biological principles, international standards and best practice for a set of 64 species assessed by ICES, using size structured assessment models. The results of the vendace specific analysis (WD8: Management strategy evaluations (MSE) of vendace in the Bothnian Bay) showed that the target F should be set at the F that brings the stock at SSB equal to 40% of B_0 (which is now defined as the target biomass reference point, B_{trg}). The trigger point when F should be reduced (i.e. $B_{trigger}$) should be set equal to B_{trg}. This allows the highest long term yield conditional on a long term low probability (less than 5%) of SSB to fall below B_{lim} (set as 15% of B_0) (WD8).

21. Report from the Reviewer

General

This is a full analytical assessment using an age and size structured population dynamics model. Input data comprise landings, a commercial CPUE index, an acoustic survey, conditional age compositions and length compositions. In addition, catch by seals is included as a pseudo fishing fleet. Stock Synthesis is the assessment software tool which provides a flexible modelling framework to configure the model to the characteristics of the available information. Importantly, the assessment does not rely on a single “best” fitting model but instead adopts an ensemble modelling approach to estimate quantities of interest and their uncertainty. Overall I found the assessment thorough and robust. As a benchmark assessment it should provide a respectable and sound scientific foundation for routine assessments on which advice can be based.

Data

The available data were comprehensively reviewed at a workshop in which the reviewer participated. Total landings from the fishery appear to be accurate and precise. These were used also to calculate a CPUE index of exploitable biomass. The index appears to track stock biomass well though no correction is made to allow for technological creep. This issue was discussed and there seems to be good reason to expect the problem is minor. When the index was calculated from a small subset of reference vessels a very similar trend in the index was apparent. The use of the index in the assessment does mean that the catch data are used twice, which is undesirable, but acceptable due to the issues with the acoustic survey (see below). One way to avoid double use of the catch data would be to use only the effort data as an index of fishing mortality as this makes essentially the same assumption of constant catchability implicit in the CPUE index.

In addition to the CPUE index, a shorter time series of acoustic data is available. The timing of the survey has changed in relation to the vendace spawning season and there is good reason to believe the catchability of the survey has changed as a result. As yet it has not been possible to correct for such changes and the acoustic estimates were included in the assessment assuming constant catchability. This is clearly a potential source of bias, though it is likely to be minor given the influence of the CPUE index in the assessment.

Catches by seals were estimated externally from the assessment itself. Their catches were derived from estimates of the number of seals, their diet and time spent foraging in the stock area. Estimates of seal numbers in recent years are considerably more uncertain due to the variability in ice cover when seals are counted. Diet studies are limited to a few years which meant that diet needed to be interpolated in a number of years. As a result, there is a large degree of uncertainty in the overall consumption of vendace by seals. This was dealt with appropriately in the ensemble by running models with three levels of seal catches.

Assessment model

Stock Synthesis (SS) was used as the assessment model framework (WD5, WD7). This is a widely used approach, especially in the USA. It has been peer reviewed and extensively tested. While it has been applied in ICES for a few stocks it is not commonly used in Europe. The underlying philosophy of SS to include the data into the model closest to the form in which it was collected, and to provide a framework for integrating a variety of different data sources. It is therefore an appropriate tool for the vendace assessment. SS is a powerful tool but does require suitable expertise to implement it effectively. I felt confident that the assessors in this assessment were well qualified to use it.

SS offers a very wide range of options and configurations. For the reference model some of the key settings were:

1. Standard errors for the fishery and seal catches, and the surveys (both CPUE and acoustic) were fixed externally. In addition, the effective sample size for the conditional age compositions (ALKs) was fixed.
2. Steepness and natural mortality were set externally based on meta-analyses of life history characteristics.
3. Selectivity for all fleets (including seals) was assumed to be asymptotic.

The consequence of 1 is that to a very large degree the log-likelihood is conditioned by the user and this directly affects the relative weighting of the data components which can be a problem with integrated models. Many practitioners estimate these standard errors as free parameters within the model allowing the data to influence the relative weight in the likelihood. This can account for process error not accounted for in the precision estimates derived from a sampling design. A model run where additional process error was estimated for the surveys failed to produce realistic results and points to a need for further investigation, since the CPUE index in particular, ought to have high precision.

Steepness and natural mortality are critical quantities in the estimation of reference points. Here steepness did appear to be estimable within the model but gave values much lower than expected from life history traits and was not therefore estimated in the final reference model. Given that a low value of steepness implies lower productivity some caution is needed in the choice of value based purely on life history traits.

Natural mortality can be estimated in SS where data contain sufficient information. This did not appear to be the case for vendace and the value was fixed but allowed to decline with size according to the Lorenzen relationship. This is the appropriate option given the inability to estimate the value within the model.

Selectivity is often influential in SS. Here the age range in the stock extends to 12 age groups where the number of fish seen at the older ages is very small. This makes estimating the right-hand side of the selection curve very difficult and the choice of logistic selection is sensible in this situation. An added complication here is that growth is assumed to be time invariant which may lead to bias in the reconstructed length distributions that influence the estimation of selectivity if there are trends in growth that result from environmental forcing. However, without strong evidence for time varying growth the assumption of stationarity is reasonable.

Diagnostics for the reference model fit were generally satisfactory. Jitter runs indicated good model convergence and the retrospective pattern indicated good consistency. The fit to the annual length compositions showed some lack of fit which may be related to growth changes, however, the fit to the cumulative length frequency summed over years was close. The CPUE index was fit well but with a tendency for the fitted values to miss the peaks and troughs of the time series; i.e. the trend was flatter than the observed values. The acoustic survey was not well fit with a clear trend in the residuals as might be expected, and very little signal in the fitted values.

Ensemble modelling

Rather than choose a single best model, which is the conventional approach in many areas (e.g. ICES), the assessment results derived here are a weighted average of results from 27 different models. These models account for uncertainty in steepness, natural mortality (excluding seal predation mortality) and the seal catch. Of particular note is that one of the criteria used to derive the relative weight given to each model is the predictive skill of the model. This is important since one of the major uses of the assessment is in forecasting biomass and catch into the future. Thus model selection is not simply dependent on statistical measures of goodness of fit but considers performance of its end use. The weights given to each model were quite similar which would suggest similar performance across models despite substantial differences in the input values and highlights the need to explore uncertainty. I felt this was a very valuable advance over conventional approaches and should lead to a more robust assessment with superior estimates of uncertainty.

One of the challenges of the ensemble approach is the demand on computing power. In this assessment the range of models in the ensemble is comparatively small and reflect the reference model configuration. It would be desirable to be able to include models with realistic but significantly different assumptions about both structure and error distributions in order to more fully explore the range of plausibility. One has to recognise, however, that the feasibility of this is limited by computing power and the present approach still represents a major step forward.

Additional model runs

During the meeting a number of additional runs were performed that examined:

- The estimability of natural mortality
- Time varying growth
- Cubic spline selectivity
- Lower CVs for the CPUE index
- Higher weight given to the age compositions
- Reduced age for plus group (8+)

Apart from natural mortality (which was not estimable) the other runs gave results that lay in the same range as the results from the ensemble so were not pursued further. While it was clear that these runs did not lie outside the range of the ensemble, it may nevertheless be the case that the cumulative effects of all these changes in a single model might lead to quite different results and there is a case for more research in this area.

Reference points

An analysis was presented that assessed the performance of a number of management reference point frameworks used around the world when applied to ICES stocks. This suggested the ICES MSY framework performed badly in comparison and that a system based on 40%B_0 as a biomass target was superior. I agree that the ICES framework is no longer adequate and agree with the proposed 40% SPR basis for reference points as this explicitly accounts for stock productivity in an internally consistent way. The ICES framework is too heavily conditioned on B_{lim} which is usually chosen on an *ad hoc* basis, often without explicit connection to stock productivity, leading to anomalies. Furthermore, the proposal to use ratio estimators (e.g. B/B_{MSY}) should be more robust as they are scale independent and facilitate the use of ensemble modelling.

Short term forecasting

The benchmark assessment is not in itself intended to be used for advice and hence the short term forecast was not fully explored. The main issue discussed was the preferred way to estimate recruitment for the short term forecast. An analysis presented at the meeting considered the performance of a number estimators based either on the stock recruitment relationship or a mean of recent recruitment values. It appeared that the Beverton-Holt stock recruitment relationship and the mean of the two most recent recruitment values gave the lowest root mean squared prediction error. The former uses biomass as the predictor while the latter assumes next year's recruitment will be similar the mean of the last two observed values. As these estimates are to some degree independent, a possible solution is to take a weighted mean. Alternatively, fitting a Beverton-Holt function with autocorrelated errors may achieve the same result. Such an approach would nevertheless require the use of the most recent recruitment residual to make the forecast.

Conclusion

I thought this a robust assessment that will provide a recipe for assessments on which advice can be based. There is still scope in the future to explore the reference model configuration and hence review the choice of models to include in the ensemble. The inclusion the ensemble approach and the proposed reference point framework are important innovations that are very welcome.

22. Recommendations for next benchmark list

Although a large array of subjects was covered during the benchmark, there are some unresolved issues that needs to be addressed during the next benchmark of this stock.

1) Stock structure
The pilot study presented at the benchmark of the genetic relationship, indicted that there might be one stock in the Bothnian bay (Swedish and Finnish). A new study with a high spatial and temporal resolution is needed in order to resolve the stock identification issue. If there is one stock of vendace the survey and catch data need to cover the entire distribution of the stock.

2) Ringed seals
The estimate of the seal predation is associated with large uncertainties, for the next benchmark there should be studies performed that are quantifying with more precision:

Population numbers
Spatial Distribution
Diet

3) Recruitment of vendace
An estimate of the recruitment of the vendace would really increase the power of the predictability of the model. In order to do that a separate Acoustic survey with focus on juveniles needs to be performed in November. In addition, other ways to estimate recruitment of vendace should be looked into before the next benchmark

4) Increasing the time series
In order to anchor the model back in time, available older catches and length frequency distributions should be scrutinised.

5) Biological parameters
One issue that was brought up late in the benchmark process was that it could be good to look into time varying maturity at age/length. Also that t seems as fecundity could be length correlated. These would prefereable be investigated more thoroughly before the next benchmark

23. List of working documents

1. **WD 1**: Bothnian Bay Vendace: Catch statistics and associated sampling.
2. **WD 2**: Vendace life history analyses.
3. **WD 3**: An evaluation report of the vendace survey in the Bothinan Bay.
4. **WD 4**: Intervjuundersökning av den elektroniska utvecklingen hos siklöjefiskare.
5. **WD 5**: Stock assessment of vendace (*Coregonus albula*) in the Bothnian Bay (ICES SD 31).
6. **WD 6**: Ringed seal predation on vendace in the Bothnian Bay.
7. **WD 7**: Ensemble model.
8. **WD 8**: Management strategy evaluations (MSE) of vendace in the Bothnian Bay.
9. **WD 9**: Genetics of vendace in the Bothnian Bay – preliminary results.

24. References

Enderlein, HO, 1986. Siklöja (Coregonus albula (L.)). Information från Sötvattenslaboratoriet, Drottningholm (1). 130 p.

Enderlein, HO, 1977. Tre siklöjemärkningar. Information från Sötvattenslaboratoriet, Drottningholm (1). 16 p.

Hentati-Sundberg, J. (2017). Svenskt fiske i historiens ljus – en historisk fiskeriatlas. Aqua reports
2017:4. Sveriges lantbruksuniversitet, Institutionen för akvatiska resurser, Lysekil. 56 s.

References referred to in the working documents can be found in their corresponding reference lists.

Annex 1: List of participants

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Annex 2: Vendace stock annex

Stock Annex: Vendace in the Bothnian Bay

Stock	Vendace (*Coregonus albula*) in the Bothnian Bay
Created	December 2021
Last updated	June 2022
Last updated by	David Gilljam, Mikaela Bergenius Nord, Valerio Bartolino, Massimiliano Cardinale , Olavi Kaljuste, Karl Lundström, Johan Lövgren, Monica Mion & Lovisa Wennerström.

A. General

A.1. Stock definition

Vendace in the Bothnian Bay (SD 31) are currently assessed and managed as two different populations: one population off the Swedish side of the Bothnian Bay and one population off the coast of Finland. This is despite the fact that the population structure of vendace in the Bothnian Bay is not well understood. Tagging studies conducted in the Luleå and Kalix archipelagos in the 1960s and 1970s show that vendace undertake natal homing, i.e. the adults return to their birthplace archipelago to reproduce (Enderlein 1977, 1986). The studies also show that vendace migrates eastwards in summer to feed in more nutritious waters, during which sub-populations/stocks from different fjords mixes (Enderlein 1986). Although the number of returns were few, some individuals were found to move all the way east to the Finnish coast (Enderlein 1986). Bergenius Nord et al. (WD: Genetics of Vendace in the Bothnian Bay, Benchmark report) sampled vendace for genetic analyses in spawning grounds in the autumn 2019 and 2020 from the river mouths of Piteå and Kalix, and in the coastal areas off Piteå, Kalix and Luleå. Vendace were also sampled during the spawning season in 2020 from two locations off Uleåborg in Finland. The study showed that samples from the Kalix River clearly differed from the rest of the samples and that the second largest genetic difference was observed between Swedish and Finnish samples. The results need to be confirmed with more samples/loci, especially from the Finnish side, in order to conclude if the differences are large enough to consider them different stocks or if vendace in the Bothnian Bay should in fact me managed as one stock. Moreover, for the appropriate management of any fish population considerations of the proportion of each component in the fisheries catch from a mixture of sub-populations is equally important as the identification of the genetic differentiations between the components. Thus, to conclude, there is presently indications, but not sufficiently strong evidence, for the separation of vendace in the Bothnian Bay into several populations for separate assessment and management. Research into this question should be prioritized to ensure genetic diversity and sustainable fisheries management of this population.

A.2. Fishery

Vendace is one of the most commercially valuable species in the regions of Norrbotten and Västerbotten (Bergenius et al. 2018). The main fishery is taking place within the Luleå, Råneå and Kalix archipelagos during five weeks in the autumn, just prior to spawning. Vendace is mainly fished with pair bottom trawling for its row, and only small amounts of the males, or the actual fish fillets of the females, are used for consumption. Fillets are instead either burned or used as animal feed. Catches of vendace with other gear are generally small, and have since the middle of the 80s rarely been more that 10 % of the total catch. Historical documentation of catch statistics show that the fishery on vendace expanded during the 1960-70s when trawling was introduced (Thoresson et al. 2001). Before this, the fishery was mainly conducted with purse seine and passive gears like nets and fyke nets. The fishery has until 1992 been conducted as a trial fishery, administered via the regions fisheries consultant in Norrbotten (Hasselborg 1995). In 1992, when the Swedish board of fisheries took over the responsibility in conjunction with that the regulations concerning fishing in the Baltic Sea and adjacent freshwater areas entered into force and the fishery became permanent. The number of licensed trawling vessels increased rapidly from the beginning of the 1960s when the trawl fishery developed and decreased from about 45 pairs in the middle of the 1970s, to 2007, after which it has remained stable at 35 vessels (17 pairs and one single trawl, WD1: Bothnian Bay Vendace: Catch statistics and associated sampling, Benchmark report).
The proportion of other species such as herring, perch and whitefish caught in the trawl fishery varies between 55 to less than 10 percent (WD1: Bohnian Bay Vendace: Catch statistics and associated sampling, Benchmark report). Recreational catch for the last 20 years are to our knowledge not quantified and expected to be small. Discarding in this fishery is assumed to be negligible.
Vendace is also caught by Finland on the Finish side of the Bothnian Bay. The total amount of landings varied between 170 and 497 in 2017 to 2020. As pointed out in section A.1. (Stock definition) and WD: Genetics of Vendace in the Bothnian Bay (Benchmark report), the population structure of vendace needs to be examined further to determine if vendace in the Bay should in fact be assessed and managed as one single stock.

A.3. Ecosystem aspects

As in Swedish and Finish lakes, the population dynamics of vendace in the Bothnian Bay is influenced by both environmental factors such as, temperature, salinity and ice cover, and trophic interactions (Marjomäki 2003, 2004, Nyberg et al. 2001). Bergenius et al. (2013) showed that the recruitment of vendace primarily is correlated to the environment (salinity and temperature), but that is is also driven by fishing and the amount of spawning stock biomass. Predation from seabirds, seals and other fish species in the Bothnian Bay, in combination with the availability of prey and the physical environment will likely also effect natural mortality of vendace, although information on these issues are scarce. One factor likely to influence the survival of vendace, and which has during the last few years been pointed at by both researchers and the fishing industry as significant, is the consumption of vendace by ringed seals (section B.5 and WD 6: Ringed seal predation, Benchmark report). The number of seals in the Bothnian Bay has increased since the beginning of the 90s and analyses for the benchmark on vendace in 2021 and earlier research show that the yearly consumption of seals is larger than the Finish and Swedish landings combined (Lundström et al. 2014). SLU Aqua has during the last few years included the consumption of vendace by seals in the stock assessment and in this way been able to estimate its effects relative to the fishery. Other factors contributing to the natural mortality are also included in the stock assessment model, but in a common parameter (M). To include the consumption of seals in the stock assessment of vendace is a significant step forward in the work towards an ecosystem approach to fisheries management, which has been called for by both SWAM and the fishing industry, and is in line with the objectives of the marine strategy framework directives and the common fisheries policy.

B. Data

B.1. Commercial catch

An overview of the commercial catches of vendace included in the assessment is provided in Table B.1. and described in more detail in WD1: Bohnian Bay Vendace: Catch statistics and associated sampling (Benchmark report). Catches included are derived from the Fiskenämnden data and official catch statistics from trawls from the Swedish Board of Fisheries (FiV) 1961 – 2002, and official trawl catch statistics from 2003-onwards from FiV/Swedish Agency for Marine and Water Management (SWAM), corrected for catches of other species using the self-sampling program (Table B.1.). Catches of vendace by other gear than trawl are estimated from data from fiskenämnden 1961 – 1993 and official catch statistics from 1994-onwards provided by FiV/SWAM. Trawl catches and catches with other gear are added to form one single series of total catch. Discarding in this fishery is assumed to be negligible, which means that the amounts of landed vendace is also assumed to represent the catch of vendace.

Table B.1. Fishery dependent catch data included in the assessment of vendace.

Data type	Years	Source
Historical Data (all gear)	1914-2013	SLU Aqua, described in Hentati-Sundberg 2017.
Official catch statistics including vendace by other gear than trawl (e.i. trawl, meaning both gear 311 and 314)	1961-2002 2003-2020	Fiskerinämnden data. Catches compiled by Thomas Hasselborg by the FiVs office for investigation (utrednings kontoret) in Luleå available at SLU Aqua. From FIV/SWAM provided yearly to SLU Aqua (Focat files)
The fishery induced self-sampling program of catch per haul for position of fishing, catch amounts, effort, species composition and proportions of old vs young vendace.	2003-2020	Filled in log sheets have been sent yearly from the majority of the fishing boat pairs to the coastal laboratory (FiV, and later SLU Aqua). SLU Aqua has a full record of these files.

The official catch statistics can be acquired from SWAM. The historical data and data from the self-sampling are available at SLU Aqua.

B.2. Biological sampling

The sampling from the trawl fishery for vendace is carried out during the fisheries five active weeks in September-October. Sampling from the catches is done from fifteen randomly selected fishing trips and boat pairs. These fifteen trips are divided in three periods, with five samples from five fishing areas during the first, third and fifth week of this period.
The catches are landed unsorted and therefore, the subsampling can take place on the landed catch, whereas it gives a representative picture of the species composition in the total catch. From each fishing trip, date, coordinates, effort data in number of trawl hours, total catch volume and the logbook page number is noted on a protocol. At each fishing trip, a random subsample (about 10 liters) is taken from the unsorted landed catch for estimation of the total catch composition in terms of size and weight. The sample must include at least 100 individuals of the most common species. All fish species in the subsample are measured by length and number per cm class is recorded. For vendace, length measurements are also separated by gender (juveniles, females, males). Total weight is given per fish species. The results are reported per species on a length measurement protocol.
From each subsample, vendace individuals are also collected for biological analysis. Biological data such as length, weight, sex, maturity (4 grade scale) and otoliths for age determination are collected from each fish. The sampling is carried out by staff from the County Administrative Board in Norrbotten, and the age determination, data entry and archiving of data and otoliths is done by staff from SLU Aqua.
For full details of the biological sampling and parameter estimation, see the Benchmark report.

B.2.1 Calculation of growth

Growth calculations are performed on combined female and male data, as no sexual length dimorphism in growth is present. To account for the trade-off between allocating energy between somatic growth and reproduction, a biphasic age-length von Bertalanffy growth curve is used:

$$y(t)=L_{inf}(1-\exp(-k(t-t_0))) \quad \text{if } t<t_1$$
$$y(t)=L_{inf}(1-\exp(-k_0(t_1-t_0)-k_1(t-t_1))) \quad \text{if } t>t_1$$

Thanks to the variation of the k rate between k_0 and k_1, L_{inf} is higher in the biphasic curve compared to the classic von Bertalanffy one (182 mm vs 154 mm) providing a better match with the L_{max} empirical data (~ 200 mm).
Fig. B.2.1 shows the age-length biphasic growth curve for the vendace in the Bothnian Bay. Exact parameter values can be found in Table C.2.

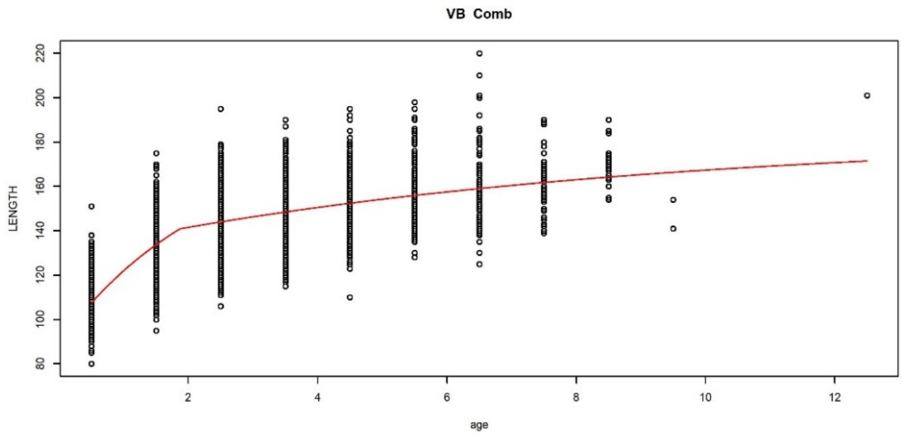

Figure B.2.1. The biphasic von Bertalanffy growth model used for the vendace in the Bothnian Bay.

B.2.2 Calculation of ALKs, LFDs and catch-at-age

Age-length-keys (ALKs) and length-frequency-distributions (LFDs) are calculated separately for the commercial and survey data. Sexes are combined. As fish from the northern fishing areas are slightly larger compared to fish from the south (Benchmark report), fishing area (north/south) is taken into account when calculating yearly ALKs and LFDs based on the commercial data. This is done by weighting the number of individuals per length- and age-class by the proportion of total landings per area and year. As the survey data is collected along transects distributed evenly across the fishing areas, weighting by area when calculating ALKs and LFDs based on the survey data is not necessary.

B.2.3 Maturity

Length frequency distributions (LFDs) of data containing maturity stage information reveal a better representation of the smaller individuals in the survey data (Benchmark report). The survey data is therefore used for length based maturity ogive estimation. All-years-combined L_{50} estimation using a binomial GLM reveals no important difference between sex (females 117 mm, males 113 mm; Benchmark report)). L_{50} for sexes combined (taking into consideration also immature individuals) is 119 mm (Fig. B.2.3).

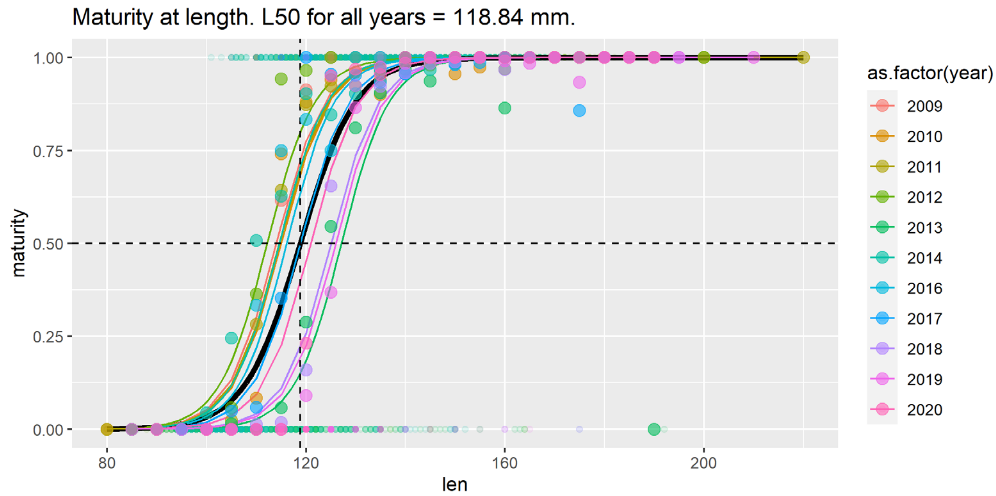

Figure 6: A binomial GLM model fit to males and female data combined, with yearly models and data (denoted by colour) and the full model for all years (thick black line). L_{50} (119 mm) is estimated to the lengths were 50% of individuals are mature.

B.2.4 Natural mortality

Natural mortality is divided in two fractions; background mortality (*M1*) and predation mortality from seals (*M2*). Age-varying M1 for the reference model is based on the methods described in Then et al. (2015) and Lorenzen (1996). *M2* is estimated by the model using time-series of vendace consumption by seals, where the consumption of vendace by the ringed seal population in the Bothnian Bay is calculated from estimates of size and spatial distribution of the seal population, together with proportion and length-frequency distributions of vendace in the seal diet (section B.5 & C.3 below).
For details on the derivation of background and predation mortality, see the Benchmark report.

B.3. Survey

Annual hydro-acoustic vendace survey have been conducted since 2009.

B.3.1 Survey area

Hydro-acoustic vendace surveys cover the north-western part of Swedish exclusive economic zone (EEZ) in the Bothnian Bay (Fig. B.1). The survey transect is approximately 225 nautical miles (n.mi.) long and covers the areas which are the most important fishing grounds for vendace fisheries.

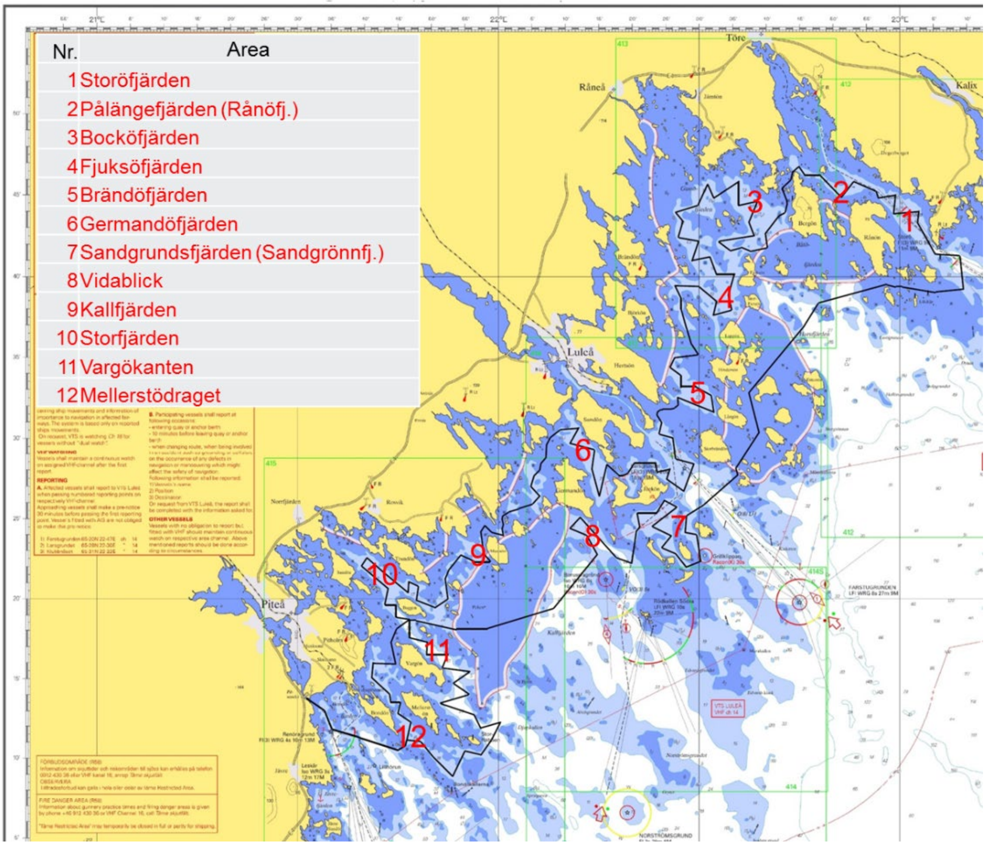

Figure B.1. Map of the survey area showing the survey transect and different sampling stations in the Norrbotten Archipelago, in the Bothnian Bay. (One minute on the latitude scale bar equals to one nautical mile.)

B.3.2 Survey timing

The timing of the survey has shifted twice over the years in order to find the optimum season for estimating the size of the vendace stock (Tab. B.1). During the first four years (2009-2012) the survey with a duration of 5 days was conducted approximately one week before the start of the vendace trawl fishing season in the middle of September (Tab. B.1). In 2013 and 2014 the survey was undertaken after the trawl fishing season - end of October/beginning of November. Since 2015 the survey has been performed during one week in the middle of October (Tab. B.1).

The acoustic investigations and control trawling were performed at day time during the years 2009-2014 when commercial vendace bottom trawlers were chartered (Tab. B.1). This was due to the fact that vendace can be caught by a bottom trawl net only in daylight when they are aggregated close to the bottom. In 2015 and 2016 a small scientific pelagic trawl net was tested on a chartered commercial herring trawler and therefore the survey was conducted at night time, when vendace are more dispersed above the bottom and somewhat easier to catch with the pelagic gear. Since 2015 the acoustic data have always been collected during the dark hours. As the pelagic trawling did not work very well, it was decided in 2017 to shift trawling of biological samples back to daytime and a commercial bottom trawl was used for that purpose.

Table B.1. Timing of the vendace survey. ("X" marks the survey week, "A" acoustics and "T" trawling.)

Year\Week	36	37	38	39	40	41	42	43	44	45	Day	Night
2009		X									A/T	
2010	X	X									A/T	
2011	X	X									A/T	
2012		X									A/T	
2013										X	A/T	
2014									X		A/T	
2015						X						A/T
2016							X				T	A/T
2017						X					T	A
2018						X					T	A
2019						X					T	A
2020							X				T	A

B.3.3 Survey design and data collection

In order to meet the survey objectives, the survey has been performed by using the mobile vertical acoustic-trawl survey method including the following components:

- systematic areal acoustic survey with zig-zag design transect to collect acoustic data covering the areas where the fish are,
- trawling to collect the biological data in order to determine the fish species composition and stock structure,
- environmental data collection for acoustic calculations and to explain distribution of fish which depends highly on salinity and temperature.

Chartered fishing vessels have been used as a survey platform for the collection of data.

Acoustic data

The acoustic data were collected using a 70 kHz Simrad EY60 portable scientific echo sounder system with down looking ES70-7C transducer (echo sounder). The transducer was mounted with a pole to the board of the vessel at app. 2 m depth. Vessel speed during the collection of acoustic data has been ~ 7 knots.

The following settings of the hydroacoustic equipment were used: output file format – raw data, ping interval – 0.3 s, pulse duration – 0.256 ms, transmit power – 400 W, range sampled - 50 m.

The survey transects were divided into 0.2 n.mi. elementary sampling distance units (ESDU), where acoustic measurements from the 5 m depth to the bottom are averaged to give one value of nautical area scattering coefficient (NASC) (Simmonds and MacLennan, 2005). However, due to the blind zone (Simmonds and MacLennan, 2005) fish that are very close (0-15 cm) to the bottom are not able to be seen. Acoustic measurements from the 5 m depth (due to the transducer depth and near-field effect (Simmonds and MacLennan, 2005)) to the bottom are used for the calculation of vendace stock size. However, due to the blind zone we are not able to see the fish very close to the bottom (0-15 cm).

Biological data

The collection of fish samples has been done to determine the species composition, length distributions and mean weight of fish species detected by the echosounder, and to collect vendace specimens for auxiliary information (e.g., age, maturity and sex).
In 2009-2014 all fish samples were taken using a commercial vendace bottom pair-trawl, for which the selection panel was removed. The vertical opening of the trawl net was 5 m and the stretched mesh size in the cod-end 13 mm. In 2015 and 2016 a small scientific pelagic trawl net (with 5 m vertical opening and 10 mm stretched mesh size in the cod-end) was tested. In 2015 no valid trawl hauls were obtained due to technical problems. In 2016 it was revealed that it is extremely difficult to perform valid control hauls using the pelagic gear. Therefore, at the end of the 2016 survey a commercial bottom trawl (with approximately 1.5 m vertical opening and 12 mm stretched mesh in the lift) was tested. Same bottom trawl was used also in both 2017 and 2018. Since 2019 a somewhat larger commercial bottom trawl (with approximately 4.5 m vertical opening and 12 mm stretched mesh in the lift) has been used.
7 fish samples from the commercial vendace bottom pair-trawl catches were used in 2015 and 2016 from the same area and time as survey for obtaining the biological data (Tab. B.2). 4 fish samples from the commercial vendace catches were used in 2020 in addition to survey hauls.
Standard haul time was 30 minutes. If the fish concentration were very high or the bottom structures are preventing the continuation of the tow, the haul time was shortened accordingly. In some cases, the haul time was prolonged due to the low fish concentrations. The plan was to cover the whole survey area more or less equally with control hauls, taking into account the areas where the bottom is suitable for trawling (the potential areas are marked on the survey map Fig. B.1).

Table B.2. Survey time, water temperature and number of samples.

Year	Start time	Mean water temperature	No of integrated elementary sampling distance units (0.2 n.mi.)	No of samples from valid survey hauls	No of borrowed samples from commercial vendace catches	Total No of length measurements	No of length measurements from valid survey hauls	No of age readings
2009	07-sep	13.8	1296	11	-	2453	2453	369
2010	11-sep	12.1	1327	12	-	2720	2720	664
2011	09-sep	13.9	1282	12	-	2702	2702	746
2012	10-sep	13.1	1266	12	-	2454	2454	765
2013	04-nov	4.0	1374	12	-	3620	3620	849
2014	27-okt	5.5	1252	12	-	2404	2404	738
2015	12-okt	7.4	1234	-	7	4122	-	1038
2016	10-okt	8.9	1192	1	7	2591	234	743
2017	09-okt	8.7	1253	9	-	1643	1643	697
2018	08-okt	7.7	1072	11	-	2158	2158	897
2019	07-okt	7.4	1062	11	-	2168	2168	880
2020	12-okt	9.4	1175	6	4	2349	1529	816

Total catch from the trawls was sorted into species in case of small catches (<70 kg), and the corresponding weight per species was registered to determine the species composition of the fish. In case of large homogenous catches, a sub-sample of ~30 kg was taken from each haul and identified and sorted by species.
In case of heterogeneous large catches consisting of a mixture of similar looking fishes (vendace, herring, smelt and small whitefish) and few different looking fishes (large whitefish, perch, ruff, etc.), the total catch was partitioned into the part of different looking fishes and that of the mixture of similar looking fishes. From the mixture of similar looking fishes, a sub-sample of ~30 kg was taken. The total weight per species for the part of the different looking fishes and the total weight of the sub-sample of mixed similar looking fishes were registered.
Length distributions were recorded for all caught fish species. For vendace and herring sub-samples containing at least 200 specimens per species (if possible) were taken from each haul to determine the length distribution by 0.5-cm length-classes. For vendace also the mean weights of individuals in each length-class were recorded. For sprat and sticklebacks, at least 100 specimens per species (if possible) were measured by 0.5-cm length-classes. For all other fish species, at least 50 specimens per species (if possible) were measured by 1-cm length-classes.

Additionally, biological samples were collected for age, sex and maturity stage determination of vendace using the following sampling key:

Length class	Minimum number of sampled individuals per haul
<12.5 cm	3
12.5-14.5 cm	5
≥15 cm	All individuals

Environmental data
Temperature and salinity were measured before the start of the survey and after each trawl haul to calculate the sound speed and attenuation (acoustic absorption coefficient) values in the echo sounder settings for the acoustics.

B.3.4 Data analysis

Abundance estimates
Echo integration method (Simmonds and MacLennan 2005) was used to provide acoustic abundance and vendace NASC estimates. The target species (vendace) is usually distributed together with other species, which makes it impossible to allocate the integrator readings to a single species. Therefore, species allocation was based entirely upon trawl catch composition. The density of fish (number of fish per 1 n.mi.[2]) was estimated for each ESDU as the product of the mean measured nautical area scattering coefficient (NASC) value divided by the mean cross section (sigma) (Simmonds and MacLennan 2005) of all fishes in the nearest haul. The mean cross section value for each haul was calculated using the following formula

$$<\sigma>=\sum_s f_s \sum_l f_{sl} 4\pi \cdot 10^{m_s/10} \cdot L_l^{a_s/10}$$

where: *m* and *a* are constants (CEN 2014, Didrikas & Hansson, 2004) for the s^{th} species, L_l is the midpoint of the l^{th} length-class (cm), f_s is the mean frequency of species *s* and f_{sl} is the mean frequency of length-class *l* for the s^{th} species in the haul. Vendace abundance density at length was calculated for each ESDU using the vendace share in the species composition and the share of the corresponding length-class in the length frequency of the corresponding haul. Average vendace abundance densities at length were calculated per ICES rectangle and 10 m depth strata. These average density values were multiplied by the area of the depth strata in the corresponding ICES rectangles and the results were summed up. Total vendace numbers at length were converted into abundances by age with help of age at length key, which was based on the biological sampling results. The acoustic vendace abundance index represents thus the number of vendace at age in the study area, i.e. the water area in the archipelago with an average depth <30 m, which is the environment that vendace prefers before spawning.

Vendace NASC estimates
Additionally, vendace NASC values were calculated by assigning the acoustic data in each ESDU with the biological data in the nearest haul. The calculation was done in the same way as the "SplitNASC" function is doing it in the StoX software (Johnsen et al 2019). The purpose of this function is to split mixed acoustic category NASC data into several single species NASC data. To split a mixed NASC value by biotic species, two things is needed:

- A normalized length distribution for each of the biotic species which the mix acoustic category represents.

- The TS-length relationship for each of the biotic species.

The following equations were used to calculate the NASC proportion for one biotic species of the total NASC of the mix category:

$$TS_{s,l} = m_s * \ log_{10} L_l + a_s$$

Where *TS* = Target strength, *s* = species, *l* = length group, *L* = fish length in cm (mean length within a length group), *m* = constant for species *s* in TS-length equation (CEN 2014, Didrikas & Hansson, 2004) and *a* = constant for species *s* in TS-length equation (CEN 2014, Didrikas & Hansson, 2004).

$$\sigma_{s,l} = 4 * \pi * 10^{\left(\frac{TS_{s,l}}{10}\right)}$$

Where σ = backscattering cross section (sigma, from one individual).

$$\omega_{s,l} = \ \sigma_{s,l} \ * N_{s,l}$$

Where ω = backscattering cross section from N individuals with the same acoustic properties and *N* = the number of individuals.

$$NASC_{s,l} \ = \left(\frac{\omega_{s,l}}{\sum_{l=1}^{n} \sum_{s=1}^{f} \omega_{s,l}} \right) * \ NASC_{total}$$

Where *NASC* = nautical area scattering coefficient, *n* = the number of length groups, *f* = the number of species and *total* = value representative for all length groups for all species.

$$NASC_s = \sum_{l=1}^{n} NASC_{s,l}$$

Based on these ESDU values the average vendace NASC values were calculated per ICES rectangle and 10 m depth strata. These average values were multiplied by the area of the depth strata in the corresponding ICES rectangles, the results were summed up and then divided by the total survey area. The vendace NASC index represents thus the average vendace NASC in the study area, i.e. the water area in the archipelago with an average depth <30 m, which is the environment that vendace prefers before spawning.

B.3.5 Survey indices

Two acoustic indices were presented for the vendace benchmark assessment: 1) survey index for vendace NASC, 2) and survey index for vendace abundance at age in the study area (Tab. B.3).

Table B.3. Survey time-series: mean vendace NASC and abundance of vendace at age in the study area.

	NASC (vendace)	Vendace abundance (mln.)								
Year	(m^2/n.mi.^{2})	0	1	2	3	4	5	6	7	8+
2009	54	14	36	17	7	6	4	2	1	0
2010	94	9	62	35	13	8	5	2	1	1
2011	141	25	84	77	25	10	5	2	1	0

2012	106	14	90	37	18	6	1	2	1	0
2013	504	762	79	160	51	16	3	0	0	0
2014	166	60	168	42	24	5	2	0	0	0
2015	400	31	142	364	50	29	4	3	1	0
2016	309	85	153	133	161	4	2	0	0	0
2017	146	31	41	54	45	31	5	1	0	0
2018	183	78	62	46	28	21	23	4	1	0
2019	165	57	85	47	17	8	5	3	0	0
2020	114	25	67	39	11	4	3	1	1	0

Conclusively, the mean vendace NASC index was used as fishery independent tuning fleet in the final assessment model.

B.4. Commercial CPUE

A commercial catch per unit effort (CPUE) series based on the complete fishing fleet, using the official catch statistics starting in 1999, is used in the assessment. Annual CPUE values are calculated as the median of the total vendance catch in kg per trip divided by the total trawling hours for that trip.

B.5. Seals

The ringed seal population size and distribution is estimated from monitoring data, telemetry data and information from literature. The ringed seal population is monitored by annual aerial line-transect surveys. The surveys cover a minimum of 13% of the entire ice covered sea area and the number of seals hauling out on the ice is calculated by extrapolating the survey strips to the entire ice-covered area (Härkönen and Heide-Jørgensen, 1990, Härkönen and Lunneryd, 1992, Härkönen *et al.*, 1998). The estimated numbers of seals on the ice are calculated from a trend line based on the 'normal' ice condition period 1988-2012, and the numbers of seals on the ice during the anomalous ice period during 2013-2020 were assumed to follow the same trend.

The proportion of the total population size being detectable on the ice is assumed to depend on the prevailing ice condition and behaviour of the seals in combination with weather conditions and time of the day (Chambellant *et al.*, 2012). No studies of haul-out fraction of Baltic ringed seals exist. The haul-out fraction during the moulting period is therefore assumed to range between 50% (upper level of the population size) and 70% (lower level) (Fig. B.5). The upper and lower population size levels for each year are calculated by dividing the trend-based estimated number of seals on the ice with 0.5 and 0.7, respectively.

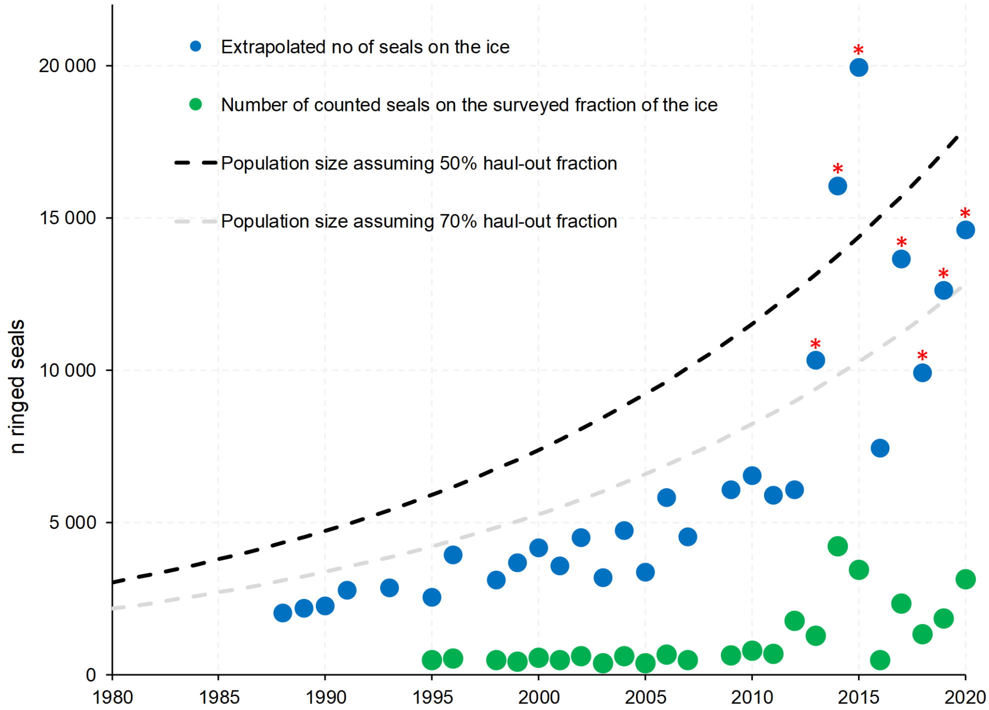

Figure B.5. Number of ringed seals counted in the aerial line-transect surveys (green), extrapolated number of seals on the ice (blue) and estimated population size based on the population growth trend 1988-2012, assuming a haul out fraction of 70% (grey dotted line) and 50 % (black dotted line). The red asterisks define years with anomalous ice conditions and accompanying incomparably high estimates of seals on the ice, excluded from the trend-curve calculation.

The prey choice of ringed seals in the Bothnian Bay is estimated from prey remains in stomachs and intestines collected from hunted seals. The average weight proportion of vendace per quarter (Q) is calculated using otolith size-fish size regressions. The proportion of vendace in Q1 was assumed to be the same as in Q2; the proportion of vendace in Q3 was assumed to be the same as in Q4, due to low sample sizes in Q1 and Q4. Years from which at least 30 diet samples were available are used as reference years (2008, 2015, 2019 and 2020, Tab. B.5), and the quarter-specific changes in vendace weight proportions between the reference years 2008-2015 and 2015-2019 are assumed to follow a linear increase or decrease depending on the data trend. The quarter-specific vendace weight proportions 1980-2007 were assumed to be equal to 2008, due to lack of data.

Table B.5. Average quarter-specific (Q) weight proportions of vendace in the ringed seal diet in the reference years 2008, 2015, 2019 and 2020. Numbers within brackets show the number of samples.

Year	Q1-Q2	Q3-Q4
2008 (n=57)	0.23	0.59
2015 (n=34)	0.23	0.49

2019 (n=45)	0.02	0.33
2020 (n=103)	0.07	0.23

C. Assessment: data, method, and settings

Assessment of vendace in the Bothnian Bay is conducted using the Stock Synthesis (SS) model (Methot & Wetzel 2013, Methot et al., 2021). Stock Synthesis is programmed in the ADMB C++ software and searches for the set of parameter values that maximize the goodness-of-fit, then calculates the variance of these parameters using inverse Hessian and MCMC methods. The assessment is conducted using the 3.30.18 version of the Stock Synthesis software under the windows platform. A range of plausible scenarios (level of vendace consumption by seals, background mortality and steepness in stock-recruitment relationships; see section *Ensemble approach* below) is evaluated using an ensemble modelling approach, which better encapsulates the variability and uncertainty exploring contrasting but plausible ranges of parameter values over choosing a single set of fixed values (Dietterich, 2000; Tebaldi & Knutti, 2009).

The assessment model of vendace in SD 31 is a one area, quarterly, length-based model where the population is comprised of 12+ age-classes (with age 12 representing a plus group) with sexes combined (male and females are modelled together).

The model starts in 1965 and the initial population age structure is assumed to be in an exploited state, so that the initial catches is assumed to be the average of preceding five years (1960-1964) in the time series. Fishing mortality is modelled using a fleet-specific method (Methot et al., 2021). Option 5 is used for the F report basis; this option corresponds to the fishing mortality requested by the ICES framework (i.e. simple unweighted average of the F of the age classes chosen to represent the F_{bar} (age 1-3)).

Model input data is summarised in Fig. C.1 and described in detail below.

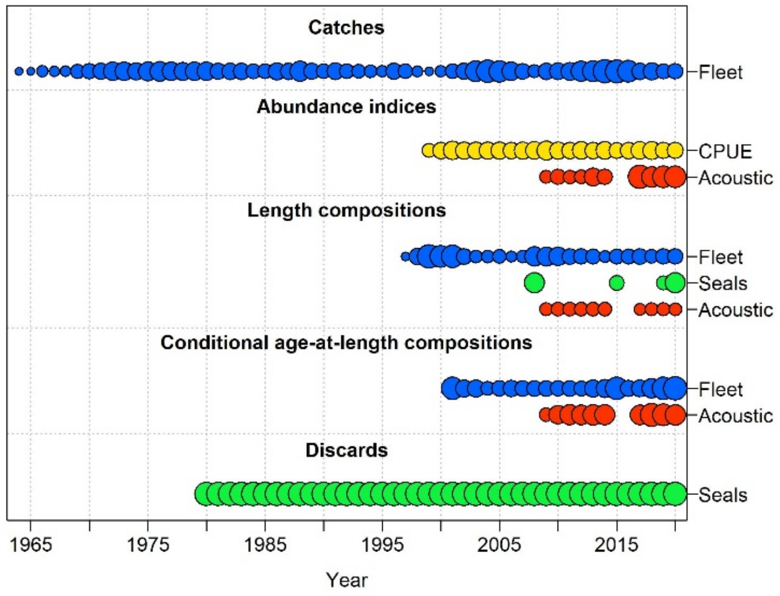

Figure C.1. Vendace in Bothnian Bay. Summary of the input time series included in the model.

C.1. Spawning-stock biomass and recruitment

Spawning biomass is estimated at the beginning of the year and is considered proportional to fecundity. In the model, the recruitment is assumed to be a single event occurring at the beginning of the year. Recruitment is derived from a Beverton and Holt (BH) stock recruitment relationship (SRR) and variation in recruitment is estimated as deviations from the SRR. Recruitment deviates are estimated from 1991 to 2020 (30 annual deviations). Recruitment deviates are assumed to have a standard deviation (σ_R) of 0.7, which was set as the value internally derived by the model. The steepness (*h*) for the SRR is set at 0.8, which is close to the value (0.78) estimated from FishLife for the species (Thorson, 2017; https://github.com/James-Thorson-NOAA/FishLife).

C.2. Growth, weights and maturity

Growth parameters are estimated internally by the model except L_{inf} which is set at 18.3 cm. Weight is estimated from a length-weight relationship (a= 4e-06, b= 3.0962) while length at maturity is described by a sigmoidal function with $L_{50\%}$ set at 11.8 cm. L_{inf}, length-weight and length at maturity parameters are fixed and derived externally using survey and commercial data (Benchmark report).

C.3. Natural mortality

Natural mortality is divided in two fractions; background mortality (*M1*) and predation mortality from seals (*M2*). *M2* is estimated by the model using time-series of vendace consumption by seals.

Background mortality (M1)

Age-varying M1 for the reference model is based on the methods described in Then et al. (2015) and Lorenzen (1996). In order to reduce the number of parameters to be used in the model, natural mortality uses 5 break at age 0.5, 1.5, 5.5, 10.5 and 11.5, with mortality values 0.27, 0.24, 0.20, 0.20 and 0.20, respectively. M1 for the adjacent ages is linearly interpolated using the values estimated for the age breaks (Fig. C.3.1).

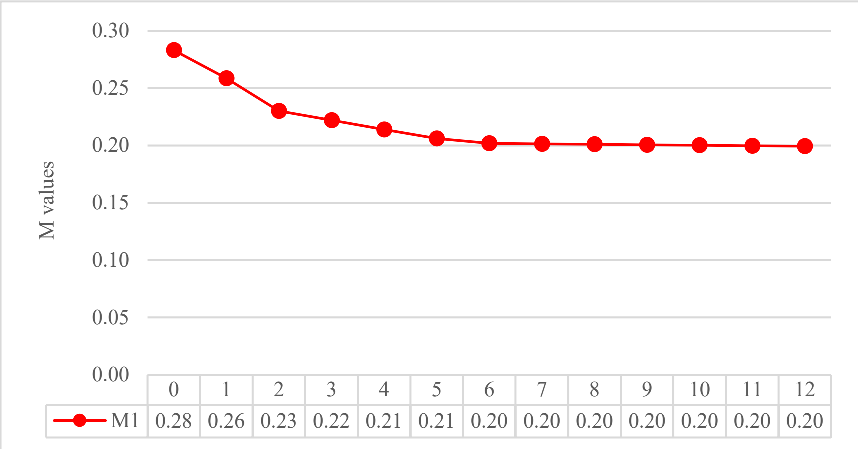

Figure C.3.1. Vendace in the Bothnian Bay. The age-specific background mortality used in the reference model.

Seal predation (M2)

The consumption of vendace (*M2*), by year and quarter, by the ringed seal population in the Bothnian Bay is calculated from estimates of size and spatial distribution of the seal population, together with proportion and length-frequency distributions of vendace in the seal diet (for details, see Benchmark report).

Using an energy consumption model (Benchmark report), the individual prey consumption is estimated to 13 MJ* day^{-1}, representing a prey biomass consumption of 2.4 kg* day^{-1}. The year- and quarter-specific consumption of vendace by the ringed seal population in the Bothnian Bay (Fig. C.3.2) is then calculated by multiplying the weight proportions (Tab. B.4) with the individual biomass consumption and the three different levels of the population size (Fig. B.4).

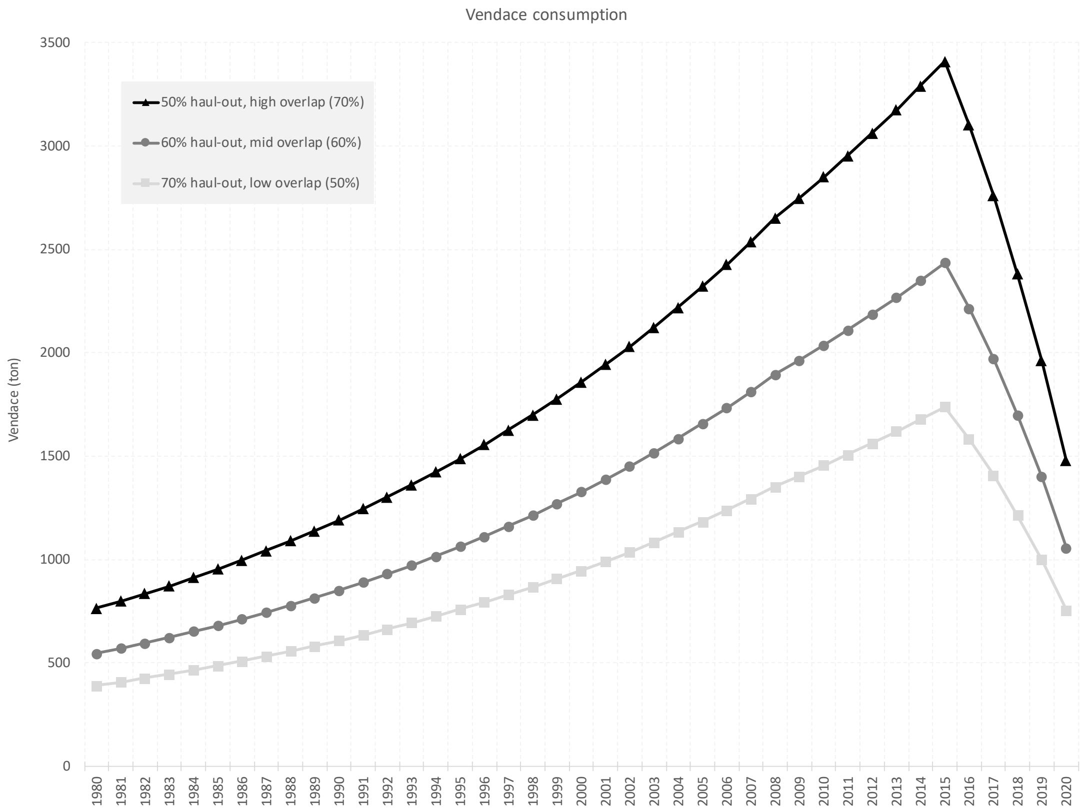

Figure C.3.2. Annual consumption of vendace (ton) by the ringed seal population in the Bothnian Bay for the years 1980-2020, estimated from different levels of size and spatial distribution of the seal population.

It should be noted that the current project for investigating the prey choice of ringed seals in the Bothnian Bay will end in 2022, and funds for a new project is at the time of the writing of this annex not available. It is also not known for how long the ringed seal monitoring programme will continue. Thus, in the event of no new seal data, a forward projection of the annual seal consumption of vendace must be done, according to what was decided at the latest benchmark (2022 benchmark report):

- If new population size estimates are available, they should be used and the historical data series of seal abundance should be updated accordingly. If no new population size estimates are available, assume a yearly increase of 4.5% from the last accepted assessment of the seal population in 2013.
- If new seal diet data from a reference year (where a full sampling of seal diet was done) is available, use that. If not, use the arithmetic average of the latest available three reference years. If there is no available reference years more than three years back, the seal data will be reevaluated in an interbenchmark.
- The average of 22% of whitefish in the vendace proportion of the seal diet should be used. If new data is available, and major changes are observed, this should be communicated with the vendace assessment working group and evaluated.

C.4. Uncertainty measures and likelihood

The total likelihood of the model is composed of a number of components, including the fit to the surveys and CPUE indices, fishery and survey length frequency data, age compositions, conditional age at length compositions and catch data. There are also contributions to the total likelihood from the recruitment deviates and priors on the individual model parameters (if any). The model is configured to fit the catch almost exactly so the catch component of the likelihood is generally small (although catch penalties might be created and catches are entered with uncertainty). Details of the formulation of the individual components of the likelihood are provided in Methot & Wetzel (2013).

C.5. Samples sizes, CVs, data weighting

For the commercial fleet, the coefficient of variation (CV) of the catches is set to 0.05. The CV of the initial catches of the commercial fleet is set to 0.1 to add extra variability. The annual sample size associated with the length distribution data is reported as number of trips sampled for commercial catches and as number of hauls for the acoustic survey.

The CV of the commercial CPUE index has an average of 0.29 over the entire time series. The CV of the acoustic survey was not considered reliable (in absolute terms, see Benchmark report) but the interannual differences were assumed to reflect the true changes in the precision of the index between years. Therefore, an average value of 0.29 is assumed for the CV of the acoustic survey, which is then scaled to retain the interannual differences.

The relative weighting of the length compositions of the base case model are estimated internally by the model using Dirichlet multinomial distribution. For the conditional age at length compositions (ALK), the sample size was manually reduced (i.e. a lambda factor of 0.01 is applied to the ALK) to match the sample size of the length compositions. This is done as the sample size of the ALK is expressed in number of aged fish while the sample size of the length compositions is in number of trips (commercial) or hauls (survey) per year. The Hessian matrix computed at the mode of the posterior distribution is used to obtain estimates of the covariance matrix, which is used in combination with the Delta method to compute approximate confidence intervals for parameters of interest.

C.6. Fishery dynamics

Fishery selectivity of the reference model is assumed to be length-specific and time-invariant. For both commercial fleet and surveys, a double-normal selectivity was used but constrained to mimic a logistic in the right side of the curve.

C.7. Ensemble approach

Instead of comparing outputs and selecting a single final model, an ensemble modelling approach (Dietterich, 2000) is used to present results with a quantitative criterion for weighting several model predictions. A range of plausible scenarios (level of vendace consumption by seals, background mortality and steepness in stock-recruitment relationships; Table C.7.1, Fig. C.7.1) is evaluated, which better encapsulates the variability and uncertainty exploring contrasting but plausible ranges of parameter values over choosing a single set of fixed values (Dietterich, 2000; Tebaldi & Knutti, 2009).

Table C.7.1. Parameters and levels employed in the final ensemble assessment grid for vendace in Bothnian Bay.

Parameter	Levels	Pregressive number of runs	Values
Seals consumption	3	3	70% haul-out & low overlap (50%); 60% haul-out & mid overlap (60%); 50% haul-out & high overlap (70%);
Background mortality *(M1)*	3	9	Lower M1: 2020 Assessment; Medium M1: Average of Lower M1 & Upper M2; Upper M1: Estimated using t-max methods;
Steepness (*h*) in S-R	3	27	0.7;0.8;0.9

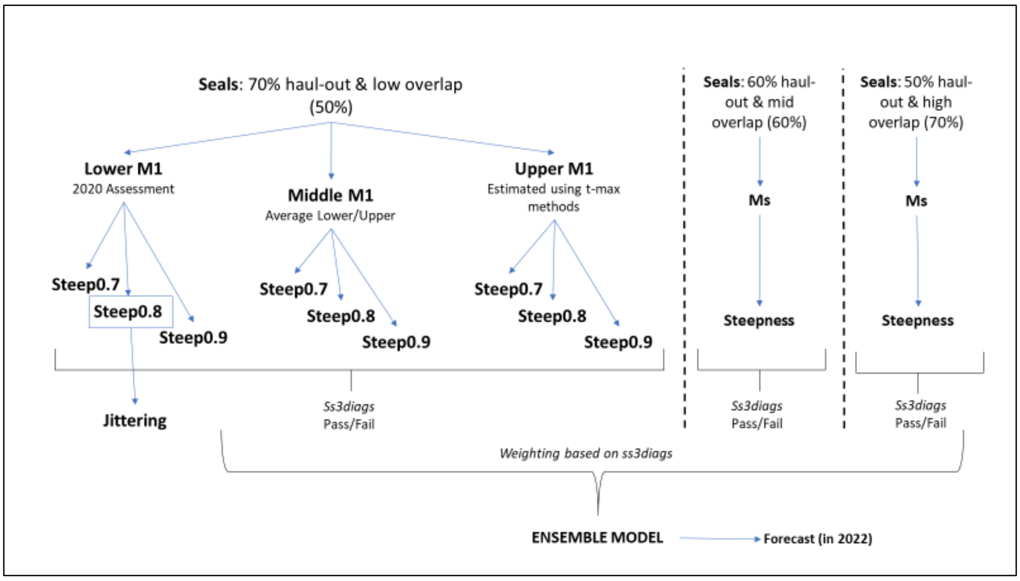

Figure C.7.1. A schematic representation of the assessment workflow for vendace in Bothnian Bay. For details on the ensemble approach, see Benchmark report.

To address structural uncertainties, the delta-Multivariate log-Normal (delta-MVLN) estimator (Walter and Winker, 2019; Winker et al., 2019) is used to generate and stich together the joint posterior distributions of plausible outcomes of target derived

quantities (e.g. SSB/SSB_target and F/F_target). It infers within-model uncertainty from maximum likelihood estimates (MLEs), standard errors (SEs) and the correlation of the untransformed quantities and it has demonstrated to be able to mimic the Markov Chain Monte Carlo (MCMC) fairly closely (Winker et al., 2019). These quantities are derived by using the delta-method to calculate the asymptotic variance estimates from the inverted Hessian matrix of the Stock Synthesis model.
The 27 grid runs (Table C.7.1, Fig. C.7.1), representing the alternative states of nature of the stock, are given weights based on interconnected diagnostics tests (Carvalho et al. 2021, Maunder et al. 2020, Kell et al., 2021), evaluating each grid run's convergence and stability, goodness of fit, consistency and prediction skill (Benchmark report). The final outputs from the ensemble model are then calculated as the weighted-median value of the 27 runs, and is used for providing scientific advice.

All model data input is summarized in table C.7.2, and reference model configuration parameters are reported in table C.7.3.

Table C.7.2. Input data used in the Stock Synthesis model.

Type	Name	Year range	Range
Catches	Catches in tonnes for each year	1965- 2020	
Lenght compositions	Catch in proportions per lenght class	Commercial fleet: 1965-2020 Acoustic survey: 2009-2020 (excluding 2015 and 2016) Commercial CPUE: 1999-2020 Seal stomachs: 2008, 2015, 2019 and 2020	8 – 25 cm
Maturity ogives	Empirical maturity at lenght estimated from commercial and survey data		8 – 25 cm
Natural mortality	Natural mortality by age class costant for the entire time series derived from Then et al., 2015 and Lorenzen 1996		0 - 12+
Surveys indices	Density index from acoustic survey and biomass index from commercial CPUE	Acoustic survey: 2009-2020 Commercial CPUE: 1999-2020	
Seal consumption	Estimates of vendace in tonnes consumed by the seals	1980-2020	
SSB index	SSB proportional to fecundity		

Table C.7.3. Settings of the Stock Synthesis assessment reference model. The table columns show: number of estimated parameters, the initial values (from which the numerical optimization is started), the intervals allowed for the parameters, the priors used (value and standard deviation), the value estimated by the model and its standard deviation. Parameters in bold are set and not estimated by the model.

Parameter	Number estimated	Initial value	Bounds (low,high)	Prior	Value (MLE)	Standard deviation
Natural mortality (M1) (age classes 0.5, 1.5, 5.5, 10.5, 11.5)		**0.27, 0.24, 0.20, 0.20, 0.20**				

Natural mortality (M2) historical (1964-1979)	1	0.21	(0, 4)	No_prior	0.09	0.024
M2 yearly deviations (1980-2020)	41					
Growth (biphasic)						
L_at_Amin	1	10.1	(3, 15)	No_prior	10.16	0.12
L_at_Amax		**18.3**				
VonBert_K_young	1	0.308	(0.05, 0.8)	No_prior	0.37	0.022
Age_K_mult	1	0.74	(0.01, 1)	No_prior	0.28	0.05
CV_young	1	0.06	(0.05, 0.7)	No_prior	0.017	0.007
CV_old	1	0.15	(0.05, 0.7)	No_prior	0.12	0.012
Length-weight						
Wtlen_1		**4e-06**				
Wtlen_2		**3.0962**				
Maturity at length						
Mat50%		**11.8**				
Mat_slope		**-1.2**				
Stock and recruitment						
Ln(R_0)	1	13.15	(9, 20)	No_prior	17.36	0.07
Steepness (h)		**0.80**				
Recruitment variability (σ_R)		**0.70**				
Ln (Recruitment deviation): 1991 - 2020	30					
Recruitment autocorrelation	1	0.3	0, 1	No_prior	0.17	0.18
Initial catches		Average of 1960-1964				
Commercial fleet initial fishing mortality	1	0.4	(1e-05, 4)	No_prior	0.063	0.011
Selectivity (double normal)						
Commercial fleet						
Size_DblN_peak_Fleet	1	14.8	(8, 23)	No_prior	15.49	0.76
Size_DblN_ascend_se_Fleet	1	2.4	(-15, 12)	No_prior	2.73	0.27
Acoustic Survey						
Size_DblN_peak_Acoustic	1	15.6	(8, 23)	No_prior	15.7	1.64
Size_DblN_ascend_se_Acoustic	1	2.7	(-15, 12)	No_prior	3.01	0.56
Seal consumption						
Size_DblN_peak_Seals	1	15.1	(8, 23)	No_prior	15.3	0.52
Size_DblN_ascend_se_Seals	1	1.44	(-15, 12)	No_prior	1.58	0.31
Catchability						
Acoustic survey (floating option)						
Ln(Q) – catchability		**-3.78**				
Trapnet survey						
Ln(Q) – catchability		**-7.91**				
Dirichlet parameters						
ln(DM_theta)_Fleet	1	4.57	(-5, 5)	Normal (0, 1.813)	4.75	0.75

ln(DM_theta)_Seals	1	3.95	(-5, 5)	Normal (0, 1.813)	4.27	0.93
ln(DM_theta)_Acoustic	1	4.20	(-5, 5)	Normal (0, 1.813)	4.61	0.84

D. Short-Term Projection

The end purpose of the short-term projection is to produce a catch options table, where the risk for the SSB of the vendace in the Bothnian Bay to go below the target reference levels (B_{target} and B_{lim}, see section E below) is shown for different levels of catch.

Short-term projections should be made with Stock Synthesis using MCMC or the delta-Multivariate log-Normal' (delta-MVLN) estimator (Walter and Winker, 2019; Winker et al., 2019). MVLN infers within-model uncertainty from maximum likelihood estimates (MLEs), standard errors (SEs) and the correlation of the untransformed quantities and it has been demonstrated to be able to mimic the MCMC fairly closely. Moreover, the ensemble approach covering the three seal predation, three natural mortality and three stock-recruitment steepness scenarios (see section C.7) should be used for the forecast, where the final output from the ensemble model is based on the weighted median value of the 27 scenarios.
Using probabilistic forecasts, catch and SSB levels corresponding to different catch options are calculated as in typical deterministic short-term forecast but using MCMC to make it possible to also include the most correct associated probability of the SSB to be below biomass reference points, for each year of forecast. Therefore, an MCMC with 1 100 000 iterations, 100 000 burn-in and 1000 thinning should be run for the different levels of assumed F in the assessment year and assessment year+1, assuming F constraint in the intermediate year. It is important to note that the given F values for the forecast will sometimes be different from the model realized F in the MCMC (but also in the MLE if this is used for the forecast). This is because the F used is an average across ages, and those ages have different F, because they are affected by selectivity. Each draw of the MCMC has different selectivity so the F produced for each draw will be slightly different. We have tested running three different MCMC with 110 000 iterations and compared the difference in F inputted and model realized F.
A stock recruitment function with autocorrelation (Beverton and Holt) should be use for the forecast. Length-at-maturity, growth (length-at-age) and weight-at-length parameters are fixed, based on the analyses performed at the latest benchmark (Benchmark report). Selectivity is constant. The amount of vendace caught by the seals during the forecast period should be set to the arithmetic average of the last 5 years for which seal predation data is available.

E. Biological Reference Points

A Management Strategy Evaluations (MSE; Punt et al., 2014; ICES 2020) framework is used to determine the target and trigger reference points used to provide advice for

vendace in the Bothnian Bay, where reference points are expressed in relative terms (relative to a fraction of B_0). Thus, reference points should be updated yearly. The latest reference points for vendace in the Bothnian Bay were calculated in May 2022 and corresponds to $F_{B40\%}$ (the fishing mortality that brings the SSB to 40% of B_0) with $B_{trigger}$ (the biomass trigger point when F should be reduced) set at 1.0 of $B_{40\%}$. This allows the highest long term yield conditional on a long term low probability (less than 5%) of SSB to fall below B_{lim} (set as 15% of B_0) (Fig. E.1).
Harvest control rules (HCRs) are kept generic and in the same form of the conventional ICES Advice Rule (ICES, 2021a), where the advice decreases from Ftrg to zero as SSB decreases from Btrigger to zero. Variations in performances of the tested HCRs are therefore determined by the parameters Ftrg and Btrigger. The HCRs were implemented using a simulated feedback control loop between the implementation system and the operating model (OM), where the implementation system translates the assessment outcome via the HCR into the Total Allowable Catch (TAC) advice.
The consistency tests are designed to identify the generic rules for specifying Fbrp, Btrg and Btrigger according to stock-specific productivity that provide the optimal trade-offs among the following two main objectives: (1) to not exceed a 5% probability of SSB falling below Blim in any single year, and (2) to achieve the highest possible long-term yields given condition (1). Consistent with the objectives of the ICES advice framework (ICES, 2020), the two objectives are interpreted hierarchically in that objective (1) is the overriding criteria of maintaining stock size above Blim with at least 95% probability, to be compliant with the ICES Precautionary Approach (PA). Conditional on objective (1), objective (2) is based on the ICES definition for using plausible values around Ftarget in the advice rule, which are derived so that they lead to minimum possible reduction from the MSY obtained by fishing at the deterministic FMSY in the long term.
The full details of the MSE analysis can be found in the Benchmark report.

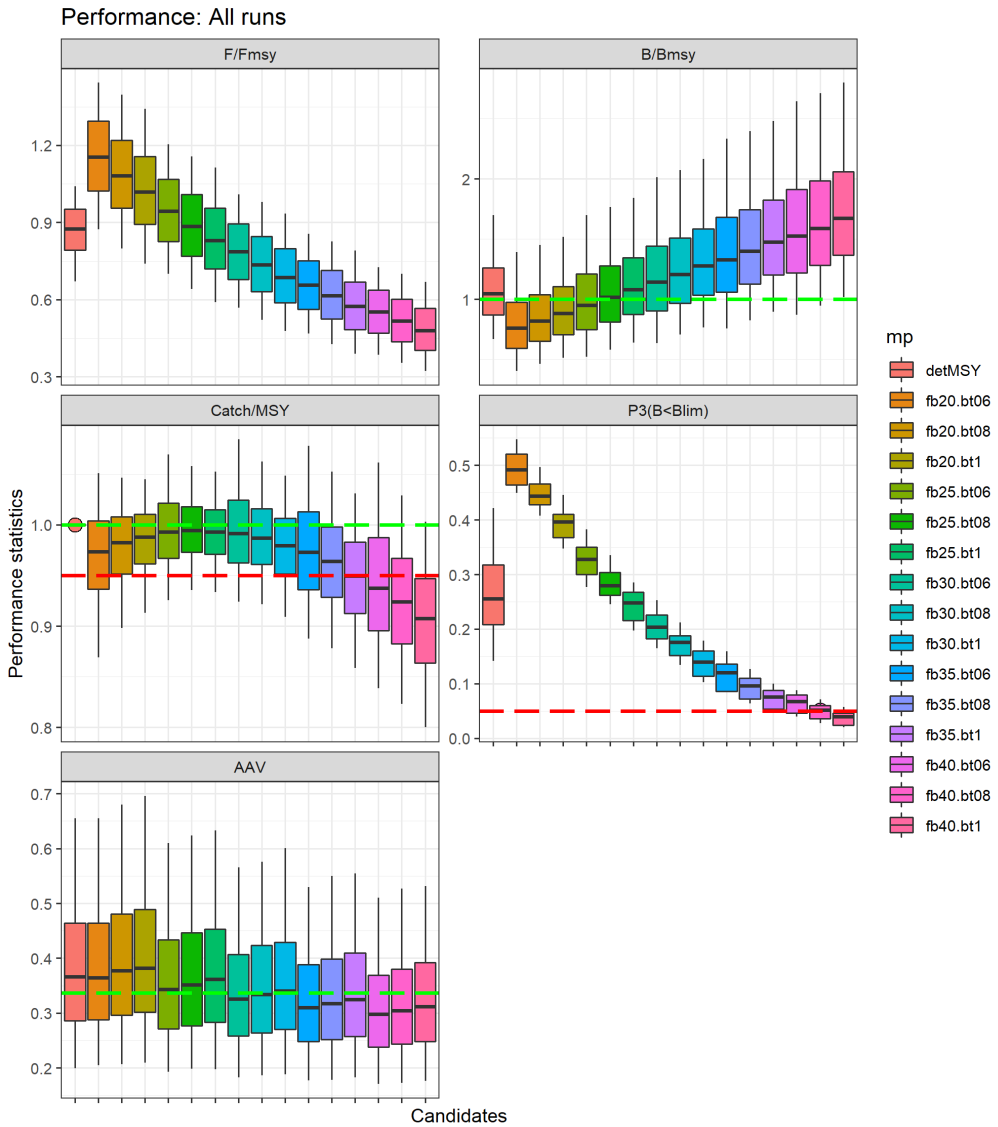

Figure E.1. Results of MSE used of evaluate reference point systems, showing the type 3 risk probabilities (P3) of SSB falling below B_{lim}, the median long-term yield (Catch) relative the median long term obtained at fixed deterministic F_{MSY} (MSY), the median long term F and SSB relative to the deterministic F_{MSY} and B_{MSY} and the median long term interannual variation in catches (AAV). Green and red dashed lines denote the target and limit thresholds, respectively. Candidates based on $F_{B\%}$ and $B_{trigger}$ as fraction of $B_{\%}$, where, e.g., fb40.bt1 denotes $F_{B40\%}$ with $B_{trigger}$ set at 1.0 of $B_{40\%}$.

H. Other Issues

None.

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Annex 3. Working documents

WD1: Bohnian Bay Vendace: Catch statistics and associated sampling

Mikaela Bergenius Nord & David Gilljam, SLU Aqua.

Table of Contents

Introduction

The purpose of this working document is to report on the catch and landings data used for assessing the vendace, *Coregonus albula*, stock in the Bothnian Bay, Sweden. First we give a brief summary of the vendace fishery. Then the recent assessment history of vendace is described and the catch time series that is used today. The main part of the work leading up to this benchmark regarding catches has been to document how the input data used back in time in the assessment have been put together from various data sources, what data sources are additionally available and from this information revise the recent time series used and extend the time series back in time. Separate sections then follow to describe various available data sources: historical catches (Data 1), catches from fiskerinämnden in Norrbotten and catches from the official logbook (Data 2), the sampling conducted by the management authority to derive the proportion of vendace from these (Data 3), and catches estimated from the self-sampling program (Data 4).

Brief about the fishery

Vendace is one of the most commercially valuable species in the regions of Norrbotten and Västerbotten (Bergenius m.fl. 2018). The main fishery is taking place within the Luleå, Råneå and Kalix archipelagos during five weeks in the autumn, just prior to spawning (Figure 1). The species is mainly fished by pair bottom trawling for its row, and only small amounts of the males or the actual fish fillets of the females are used for consumption. It is either burned or used as animal feed. Historical documentation of catch statistics show that the fishery on vendace expanded during the 1960-70s when trawling was introduced (Thoresson m.fl. 2001). Before this, the fishery was mainly conducted with purse seine and passive gears like nets and fyke nets. The fishery has until 1992 been conducted as a trial fishery, administered via the regions fisheries consultant in Norrbotten (Hasselborg 1995). In 1992 the Swedish board of fisheries took over the responsibility in conjunction with the regulations concerning fishing in the Baltic Sea and adjacent freshwater areas entered into force.

The number of licenced trawling vessels increased rapidly from the beginning of the 1960s when the trawlfishery developed and decreased from the middle of the 1970s to 2007, after which it has remained stable at 35 vessels (17 pairs and one single trawl, Figure 2).

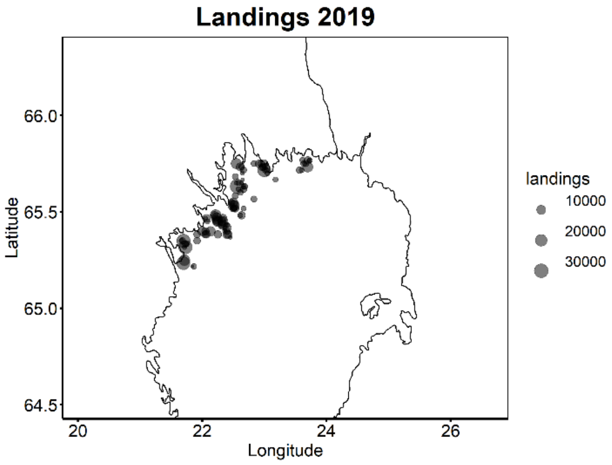

Figure 1. The distribution of vendace landnings/catch in the Bothnian Bay for 2019 as an example.

Figure 2. Approximate number of active trawl pairs with a license to fish for vendace in the Bothnian Bay.

History of catch data and assessment

The landings data time series of the assessment used until now of vendace in the Bothnian Bay start in 1991 (Figure 3). Note that from hereon we are using catch and landings intermittently, as we are not aware of significant amount of discarding in this fishery. The years 1991-2002 of this time series, are based on official catch statistics (Table 1, Data 2) reported by fishers to the management authority (at the time, Swedish Board of Fisheries (FiV) and from 2011 Swedish Agency for Marine and Water Management (SWAM)). It is not entirely clear exactly how these catches are derived, but the catch was corrected by the authority for the catch of other species caught (by catch) in the trawls based on the authorities sampling program of the catch (Table 1, Data 3). This sampling program has been undertaken from at least 1994, from which year there has been yearly assessments reports of the stock, albeit variously extensive and variously available. From the reports it is apparent that for 1991-2002 not only the catches from the pair trawling in September-October have been included, but also the catches from other gear, such as nets and traps. In 2003 (this is somewhat uncertain) until 2010 the fishery self-sampling program (Table 1, Data 4) was in place and the total catch of vendace and other species was reported by the fishery and sent to FiV for analysis. The assessment of the stock was a joint effort between FiVs "utredningskontor" in Luleå and its research laboratory in Öregrund. In 2011 FiV was divided into separate entities for management and research and became SWAM and SLU Aqua. SLU Aqua was from thereon contracted by SWAM to undertake the assessment and give biological advice for fishing opportunities. Since 2002 up until now it appears that catches of vendace in other gear has not been included in the assessment (Table 1). The amounts caught in other gear has in recent times generally been small (~95%, see section on Catches of vendace from other gear and notes on recreational fishing) and it is unlikely these would have changed the recent time perception of the stock. The self-sampling program has been variously effective (See section Self-sampling program of fisheries catch) and in 2011 analysts complemented the information on total catch used in the stock assessment with catches from the official catch statistics (Data 2). The information from the self-sampling program was still used to correct for bycatch. Between 2011-2014 only catches from licensed (to fish vendace) pair trawlers were included, between 2015-2019 this was extended to catches from licensed boat pairs using both pair- and single trawling (Table 2). In 2020 all vendace caught with pair- and single trawling were included, irrespective of whether these had licenses or not. The aim of this benchmark is now to look over the catches that have been included previously in the assessment, update these when possible and complement the trawl catches with catches from other gear, so that all catches of vendace in the Bothnian Bay are included in the assessment.

Various types of assessment analyses have been undertaken through time for the vendace stock in the Bothnian Bay. The type of advice has consequently also changed over time; from a data limited approach with an advice on opportunities for increasing or decreasing catches to a fully analytical advice approach with reference points and associated probabilities of falling below these points. It is beyond the scope of this benchmark to describe all these, but here we give a brief overview of the approaches from more recent times. At least from the beginning of 2000s a VPA (cohort analysis) has been undertaken. During the early 2000s the VPA was also complemented with stock estimate calculations based on catch amounts and efforts. In 2014 and 2015 (i.e. 2013 and 2014 last year of data) a state-space assessment model (SAM, Nielsen and Berg, 2014) was run in parallel to the VPA. In 2015 a TAC advice was given for the first time, based on the ICES precautionary principle (PA) for data limited stocks (the 2/3 rule based on SSB as a stock index).

In 2016 the ringed seal predation was included as a fishing fleet into the SAM model for the first time (with scenarios of high and low seal numbers) and the TAC advice still based on PA approach. In 2017 new reference point were computed for each of the high and low seal number scenarios and the TAC advice for 2017 and 2018 were provided based on the fishing mortality which would provide maximum sustainable yield (Fmsy). Associated probabilities of falling below the biomass reference point Blim were also provided. In 2019 the stock assessment was based on Stock Synthesis Statistical framework (SS3, Methot and Wetzel 2013); new reference points were computed and the advice based on Fmsy. In 2021 a new biomass management target (Btarget), with an associated acceptable level of risk of falling below this target, was decided in discussions with the fishery and SWAM. The advice for 2020 and 2021 were therefore based on the catch for which the probability of falling below Btarget was less than 5%.

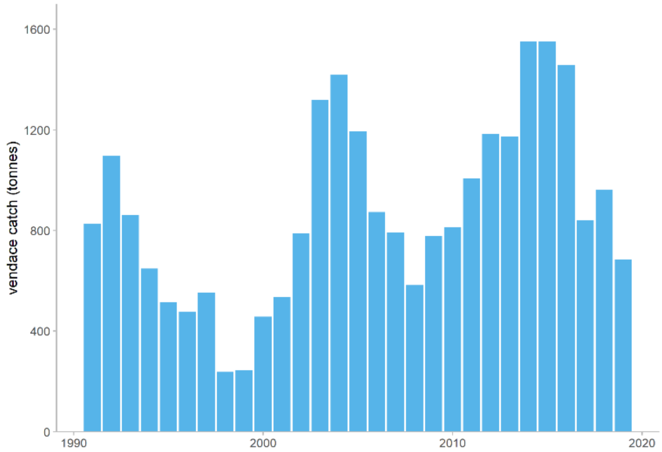

Figure 3. Landings used in the assessment of vendace up until the last assessment in 2021 (base case).

Table 2. Summary of which data have been used in the assessment as a basis for total catch, the data have been used to correct for bycatch of other species and whether catches from other gear that trawl have been included or not. Gear 311 = pair bottom trawl, 314 = single bottom trawl.

Years	**Catches from other gear include**	**Basis of catch before correction of other species**	**Basis of correcting for other species**
1991-2002	YES	Catches from official catch statistics (Data 2)	FiVs sampling program (Data 3)
2003-2010	NO	Catches from self-sampling program (Data 4)	self-sampling program (Data 4)
2011-2014	NO	Catches from self-sampling program (Data 4) and official catch statistics (Data 1) for gear 311 and licensed boats	self-sampling program (Data 4)
2015-2019	NO	Catches from official catch statistics (Data 2) for gear 311 and 314 for licensed boats	self-sampling program (Data 4)
2020	NO	Catches from official catch statistics (Data 2) for gear 311 and 314 for all boats	self-sampling program (Data 4)

Historical official catch statistics (Data 1)

Up until now, the catch data included in the assessment go back to 1991. Around 2017 however, a database was put together by SLU Aqua of Swedish official landing/catch statistics from the early 1900s and up until recent times (Table 3). The methods used to derive this data are briefly described in Hentati-Sundberg (2017), who reports on the development of the Swedish fishing industry from a social-ecological system perspective. Hentati-Sundberg describes that Sweden developed in the beginning of the 1900s a cohesive way of collecting statistics of fishing in marine waters, including all fishing on the Baltic Sea coast, Skagerrak and Kattegat (2017). Before this, since the middle of the 1800s, catch statistics had been collected regionally both along the west coast and for parts of the Baltic Sea. The first yearly book of Swedish fisheries statistics was then published in 1914, and the way that the statistics was reported in this book changed very little until the end of the 1960s (Hentati-Sundberg 2017). The reporting only covers the part of the landings that has been sold, i.e. not what has been thrown back in the sea, landed or sold unofficially. The sold landings have also been registered based on the place where the fisher lived, not from where it has been fished. As long as the fishing was conducted locally the reporting in this was relatively representative of the actual place of fishing (Hentati-Sundberg 2017). However, as the fishing industry started to fish in areas further from home and the discussions in the international arena leaned towards international management of the fish stocks, the demands on the geographical distribution of the fisheries increased (Hentati-Sundberg and Hjelm 2015). Starting in the end of the 1960s and during the 1970s the requirements of fisheries statistics increased and gradually a logbook system was implemented, for which the catch had to be reported based on gear and area (Hentati-Sundberg 2017). At the same time the surveillance of sales at the fish auction and other first-hand receivers of fish. This system with logbooks and sales statistics (from 1986 onwards) of landings is the system we have today. The time series of vendace landings from 1914 to 1962 proposed to be included into the vendace assessment is taken directly from this database and we assume catches from all gear are included. While the data are not cross-checked with the reports in the National Archives, and Hentati-Sundberg (1917) cannot ensure no possibly reporting and systematic errors, he points out that the data will give a description of the long-term development of the Swedish fishery, and thus the catch of vendace. It is worth noting that the catches of vendace between 1914 and 1985 are also presented in a diagram in Enderlein (1986) and these agree well with those in the SLU Aqua database.

Figure 4 gives a historical overview of vendace caught in the different counties/regions of Sweden. Sea based vendace has apparently been reported in many regions back in time, albeit with catches so small these are not visible in the Figure 4. Although we only use landings from this database for the years 1914 -1962 in the assessment, for interest we show the entire available time series. The largest catches are reported in the regions of Norrbotten, Västerbotten and Västernorrland from which the largest catches are also expected considering the availability of sea based vendace (Figure 4). We propose to only include historical catches of vendace from Norrbotten and Västerbotten, however, as we do not consider the vendace stock in Västernorrland to be connected to these other two regions. The landed catch in the Gävleborg region visable in Figure 4 is not considered here as it is questionable and also reported in Bothnian Sea. It is apparent that while herring dominated the catches in Västerbotten and Norrbotten up until the early 1970s, the vendace trawl fishery developed during the 1960s, as the trawl fishery was introduced (Thoresson m.fl. 2001), and vendace dominated the catch in the 1970s (Figure 5). Between the 1980s and the early 2000s vendace and “skrapfisk” which may indeed be herring, were landed in about equal amounts, after from which vendace has dominated the catches (Figure 5). It can be noted that the trawlfishey for vendace was only allowed in the end of the 1950s with special licences as a trial fishery, until it became part of the FiVs regulations and permanent in 1992 (Annex 1).

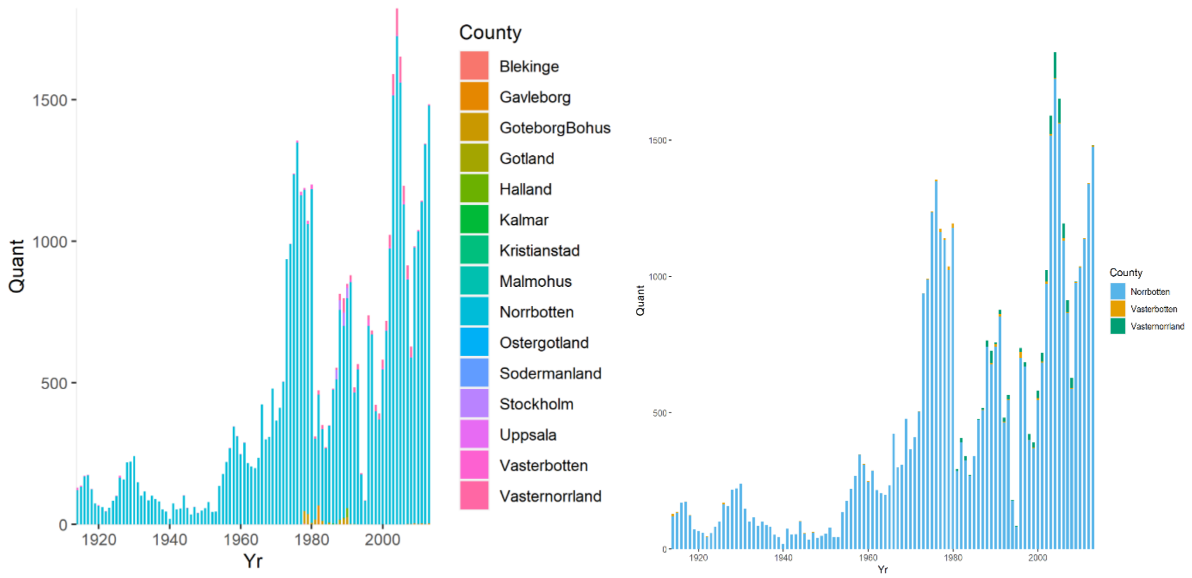

Figure 4. Historical catches (1914 – 2013) of vendace per region (left panel) and per the main three reporting regions (right panel).

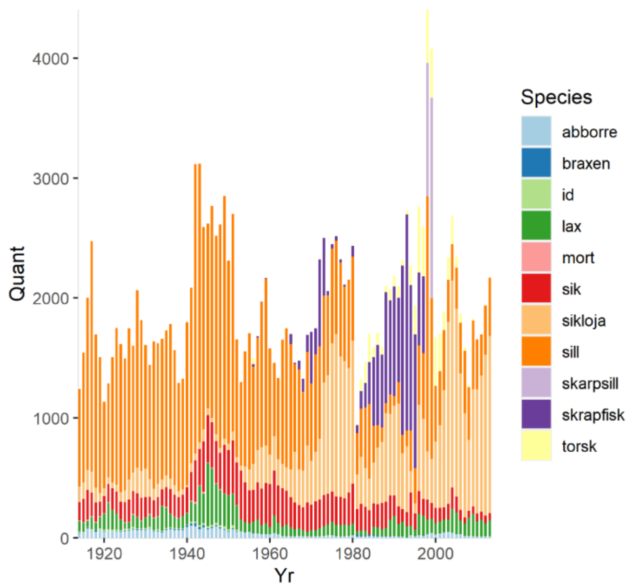

Figure 5. Catch of the most important (in weight) species reported in Västerbotten and Norrbotten 1914 – 2013. (The cut-off between important and non-important species was arbitrarily drawn based on catch weight).

Table 3. Fishery dependent catch data from trawl available for the vendace benchmark in 2021.

Data type	Years	Source
Historical Data (Data 1)	1914-2013	SLU Aqua, described in Hentati-Sundberg 2017.

Official catch statistics including vendace by other gear than trawl (Data 2)	1961-2003 1999-2020	Fiskerinämnden data. Catches compiled by Thomas Hasselborg by the FiVs office for investigation (utrednings kontoret) in Luleå. (Annex 1) From FIV/SWAM yearly provided to SLU Aqua (Focat files)
Fiv/SLU Aqua sampling of catch composition and lengths (Data 3)	1998-2020	Reports sent yearly by the FiVs office for investigation (utrednings kontoret) in Luleå; later the county administrative board in Norrbotten; to the coastal laboratory (FiV, and later SLU Aqua). The data have been transferred into excel sheets and during this benchmark these have been combined into csv files. These data are not since 2003 used to correct the official catch statistics. Instead Data 4 are used.
The fishery induced self-sampling program of catch per haul for position of fishing, catch amounts, effort, species composition and proportions of old vs young vendace. (Data 4)	2003-2020	Filled in log sheets have been sent from the majority of fishing boat pairs to the coastal laboratory (FiV, and later SLU Aqua). The data have been transferred into excel sheets and during this benchmark these have been combined into csv files

County statistics and official logbook (Data 2).

During the 1950-60s, until 1986, when the official logbook was introduced, the trawl landings of vendace were first collected by Hushållningssällskapet, and later fiskerinämnden in the Norrbotten county[1] (Table 3). Reports were sent in by fishers or data collected from fishers by county employees (länsfiskekonsulenter; Hasselborg per. com. 2021). Figure 6 presents vendace catches caught by trawls as reported by fiskerinämnden and since 1986 by the official logbooks, corrected for other species caught in the trawls as described below. The file has been compiled by Thomas Hasselborg, a former employee at the Norrbotten county board, and the entire table of data is available in annex 1). These data are considered more reliable than the historical catches (Data 1) presented above (Hasselborg pers. com. 2021, Enderlein 1985) and will therefore be used from 1963 until 2002. From 2003 and onwards, the official data logbook data will still be used, but from here on these are corrected for other species with data from the self-sampling program (Data 4); compiled by SLU Aqua (Table 3).

[1] Before 1991 it was the 24 fiskerinämnderna together with Fiskeristyrelsen that collected fishery statistics, In 1991 Fiskeristyrelsen became Fiskeriverket and the fiskerinämnderna became part of the county boards. =

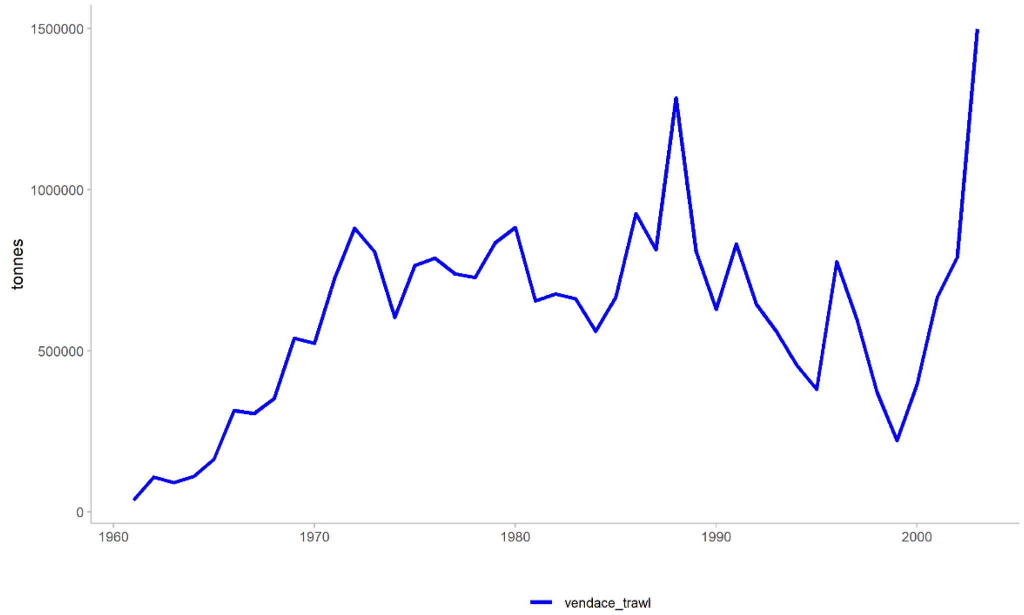

Figure 6. Total vendace trawl catch from the official catch statistics as compiled by Fiskenämnden, FiV and länsstyrelsen for the years 1961 – 2003 (Data 2; Table 3).

The official catch statistics readily available to the vendace benchmark starts in 1994 (Data 2 cont, Table 3). In difference to the historical and "fiskenämnden" catches presented above, the recent official logbook statistics generally provides information down to the haul level with regards to date, total catch, catch of different species, gear used and effort (among many other details). These data have been provided yearly to SLU Aqua from SWAM (previous the Swedish Board of Fisheries (FiV)). It is beyond the scope of this text to describe how these data have been collected and compiled and further details can be provided at SWAM (https://www.havochvatten.se/en/policy-and-regulation/commercial-fishing/catch-statistics.html#h-CatchDataSince1999). The official catch statistics provide estimates of total catch (also included other species) and the fishers estimate at sea of vendace catch caught per year (Figure 7 for the period 1999-2020).

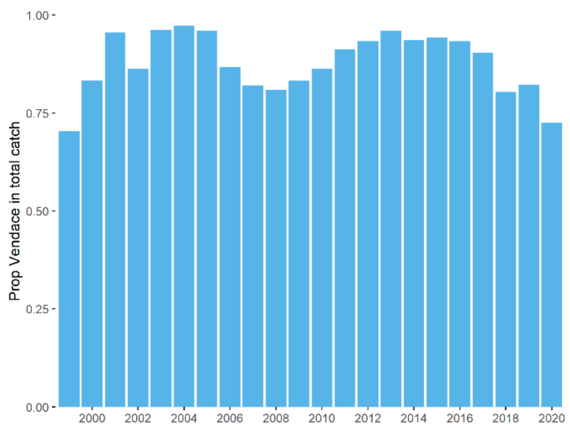

Figure 7. Reported total catch and vendace catch (left panel) and proportion of vendace in the total catch (right panel) from the official catch statistics (Data 2; gears pair bottom trawl (code 311) and single trawl (code 314)) years 1999-2020.

A problem that arose with the introduction of the official logbook in 1986, was that the vendace trawl fishery now had to start estimating and report the proportion of vendace in the total catch out at sea. Later in the harbor, the catch should be weighed and each species reported separately, but this has rarely been done. In reality, separate declarations of landings are therefore missing and are simply copies of the official logbooks and the official landings of vendace is believe to generally overestimate the amount of vendace landed (Figure 7). Consequently, the acting management body started in the end of the 1970s to take samples of the catch for species composition, length and age distributions, so that the amount of vendace in the catch could be more correctly estimated (Data 3). The main focus areas at the start of the sampling were Kalix and Luleå, but this changed over time. Already in 1996 the sampling was conducted in the five main archipelagos of fishing Haparanda, Kalix, Råneå, Luleå och Piteå. Extra samples were taken from boats that had been fishing within the archipelagoes, in one or several of the bays where the fishing was more intensely conducted. The material was generally collected from the boats in the harbors, spread over the time of the fishing period in September-October. While the species composition and lengths were registered from fresh samples, the individual sampling for age, weight and maturity was conducted in the laboratory on frozen material. The sampling design and methodology is covered in more details in the working document on biological parameters (WD on biological parameters).

Self-sampling program of fisheries catch (Data 4)

In 2001 fishers also started to keep records of species composition and proportions of adult and young vendace per trawl haul (Hasselborg m.fl. 2001, Data 4, Table 3). In 2001 these samples only covered few of the boat pairs and 17% of the fishing operations. In 2002 however, the sampling covered 94% of the fishing days and can be considered representative (Hasselborg 2004, Gårdmark 2007). Thus, it is our understanding that between the end of the 1970s until 2002 the catch amount of vendace has been estimated based on the official catch statistics, multiplied with the proportion of vendace in the management authorities samples from the catch (Data 3).

From 2003 and onwards, when the self-sampling program (Data 3) was fully operationalized, the coastal laboratory (first FiV and later SLU Aqua) took over the estimation of the total catches of vendace that go into the stock assessment (Table 3). From then (2003) until now, the coastal laboratory sends out structured log sheets to all active par trawling teams, in which they register for each haul the date, position, total catch, and catch composition based on a sample from the catch (Annex 3). These reports have been used both to estimate total catch of vendace and to correct the total catch for bycatch of other species (Table 2, Figure 8). The response rate with regards to sending in the logbooks has been varied over time, but has in general been high (>90%). For each year there are generally more than 200 hauls sampled for information about the catch (Figure 8). It has to our understanding been compulsory since the early 2000s. The number of hauls reported by each trawl pair in the self-sampling book in comparison to the actual number of hauls conducted has also varied, but at this point we have not analyzed the extensiveness of this discrepancy.

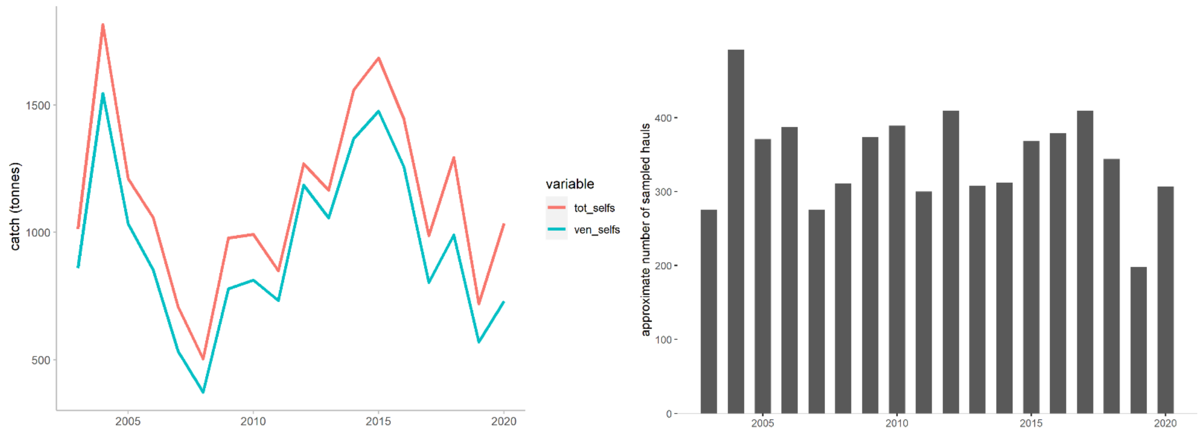

Figure 8. Left panel: Total catch and estimated catch of vendace by year from the self-sampling data. Right panel: Approximate number of hauls for which catch and species composition have been reported per year.

What should be noted and paid some extra attention to is the discrepancy between the total catch amounts in the official catch statistics (Data 2) and that of the self-sampled catch (Data 4, Figure 9). The self-sampling program was indeed put in place to better estimate the proportion of vendace and thus the catch of vendace in weight, but we are not clear on why the total catch differ to such extent. This was discussed at the benchmark meeting but could not be clearly explained. The difference between the vendace catch reported in the official logbooks (Data 3) and the vendace estimated in the self-sampling program (Data 4) can be seen in Figure 10, in which the catch data from the old assessment are also shown for comparison.

Figure 9. Total and pure vendace catches per year as reported in the official catch statistics (tot_loggb and total catch from the self-sampling protocols (tot_selfs).

Figure 10. Total and pure vendace catches per year as reported in the official catch statistics (vend_loggb), total catch from the self-sampling protocols (ven_selfs) and the catch used in the assessment base case.

We understand from the various internal reports between 2003 and 2020, that up until about 2011 the total catch, for which the catch of pure vendace should be derived from, was based on the self-sampling program only. Between 2011 and 2016 the total catch was primarily taken from the self-sampling program, but when vessels underreported, catches for these vessels were complemented from the official logbooks, after which the correction factor from the selfs-sampling program was applied to get pure vendace catch. From 2016, after discussions with the fishing industry, the total catch was derived from the official logbook only and the self-samples were used compute the proportion of vendace in the catch. The catch estimate used for the assessment (the red line in Figure 10) should be fairly close to the vendace catch estimated from the official catch statistics (blue line) early in the time series and to the self-samples (green) at in the end and the start of the time series. As the way the catch proportions have been used has varied (e.g. corrections for by week, by haul or boat pair) these cannot be expected to be exactly the same. The larger discrepancies between the assessment catches used and the vendace estimate based on the self-samples for the middle part of the times series, and the differences between the total catches of the official logbook and the total catches from the self-sampling program was discussed at the meeting. The fishing industry proposed to use the catches from the official logbooks as the basis for total trawl catch for the entire time series 2003-2020. It was consequently decided to use the total trawl catches (in trips of which vendace have been caught) from the official logbooks multiplied by the proportions of vendace from the self-sampling program for inclusion in the assessment, and thereafter add the catches of vendace in other gear (Figure 11).

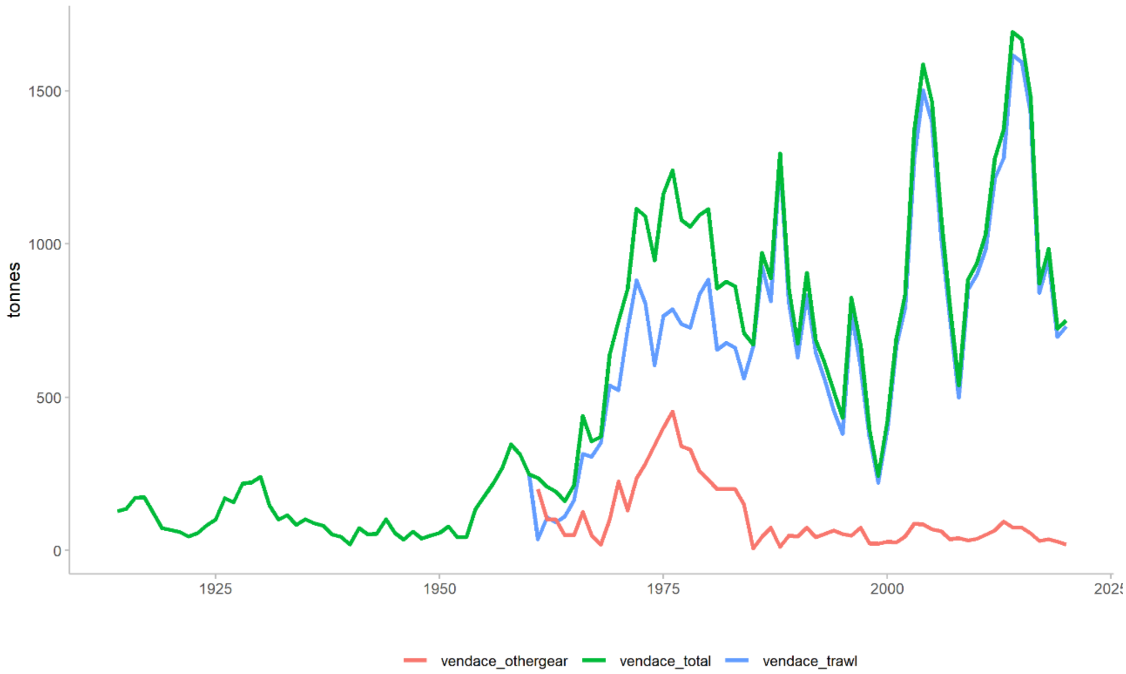

Figure 11. Vendace catch data for the new assessment. Vendace_othergear (red) show official catch statistics of vendace 1961 – 2020 and vendace_trawl (blue) show official catch statistics of vendace in trawls from fiskenämnden 1961-2002 and Fiv/Swam data 2003-2020 are multiplied by the proportions of vendace from the self-sampling program. Vendace total (green) show historical catch 1914 – 1960 and vendace_othergear+ vendace_trawl from 1961 2020.

Catches of vendace from other gear and notes on recreational fishing

It has become apparent that at least from 2003 and onwards catches of vendace in other gear have not been included in the assessment (Table 2). Only catches from pair bottom trawling (gear code 311) have been included, and in later years also catches of vendace with single trawls (gear code 314). The aim now is to include catches from other gear as far back in time as possible. For the historical catches (Data 1) the data are not provided by gear, but we assume that the reports for the counties include all catches of vendace, i.e. from all gear. Catches of vendace by gear is however available for parts of the time series in official catch statistics between 1961 – 2020 (Data 2; Table 4). Actual numbers were not available for all years, and for these years vendace catch taken with other gear than trawl were estimated from the figure presented in annex 1. Catches with other gear were quite substantial in the late 50s to the late 80s, and this was particular catches with purse seines (Figure 13). Purse seine fishing has been taking place since the beginning of the 1900s, but it was in particular the use of this gear that increased at the same time as the trawl fishery developed, until it was phased out in the late 80s (Data 1). It should be pointed out that the amount of catches from other gear during the earlier part of the time series (1961 to about 1995) are rather uncertain (see for example Enderlein 1986). This is because we are unsure if these data thus include both the part-time commercial fishing and recreational fishing catches and if this has been consistent over these years in the time series. Recreational fishing seems to have been quite substantial before the trawl fishery started, and was for example, assumed to be 10-12 % of the commercial fishery between 1995-1993 (see Statistik om det Norrbottniska siklöjefisket in Annex 1). Catches of vendace with other gear are however, currently generally small (Figure 14), and has since the middle of the 80s rarely been more that 10 % of the total catch and never more than 100 tonnes (Figure 13, 14). Recreational catch for the last 20 years are to our knowledge not quantified and expected to be small. For a full description of the gear codes see annex 3, but to summaries it is mainly passive gear such as nets and fyke nets that are used today besides trawls.

Table 4. Available official catch statistics of vendace caught by other gear than trawl (Data 2)

Years	**Data available**	**Assumption made**	**Source**
1961-1970; 1981-1984	NO	Catches with other gear taken from eyeballing a figure provided by länsstyrelsen Norrbotten	Statistik om det Norrbottniska siklöjefisket (Fiv, Utredningskontoret Luleå annex 1).
1971-1980; 1986 -1992	YES	NA	Official catch statistics compiled by Thomas Hasselborg by the FiVs office for investigation (utredningskontoret) in Luleå.
1993	NO	Catches with other gear assumed as an average of 1992 and 1994	In consultation with Thomas Hasselborg pers. com. 2021
1994-1998	YES	NA	Official catch statistics from FIV/SWAM to SLU Aqua (separate send-out from Jarl Enqvist 211104 to Mikaela Bergenius Nord)
1999-2020	YES	NA	From FIV/SWAM yearly provided to SLU Aqua (Focat files)

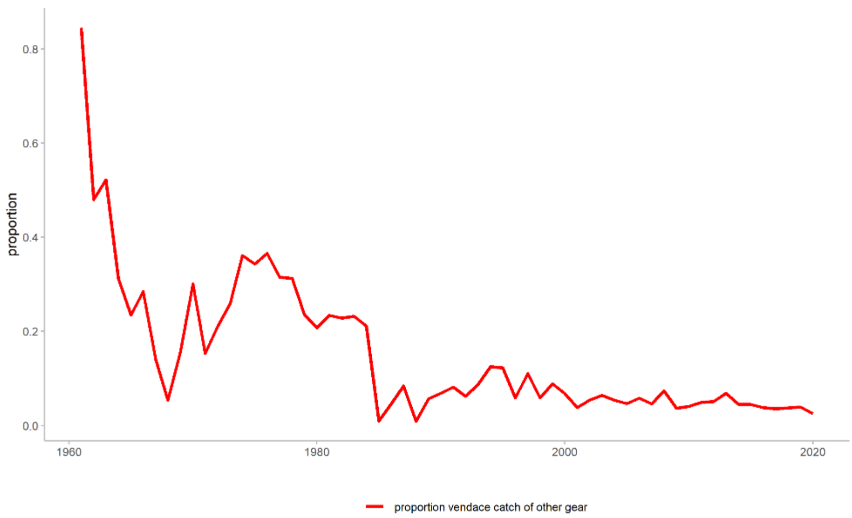

Figure 13. Proportion of total of catch of vendace caught by other gear than trawl in the Bothnian Bay. Based on the official catch statistics 1961-2020 (Data 2).

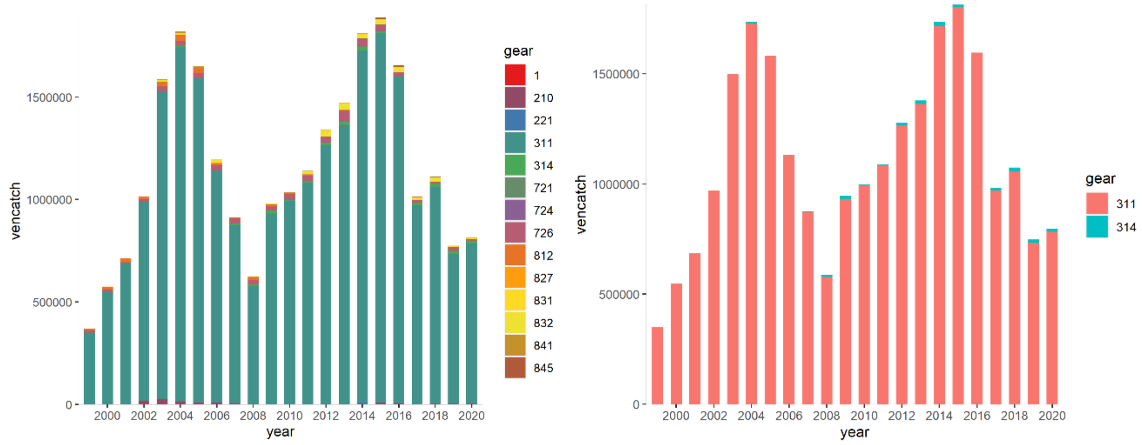

Figure 14. Catch of vendace by gear in the Bothnian Bay. Based on the official catch statistics 1999-2002 (Data 2). All gears (left figure); pair bottom trawl (311) and single trawl (314) (right figure).

Conclusion

The catch data used so far in the assessment have been revised based on the addition of several new data sources and reasoning with stakeholders (see annex 4 for the new catch data series and sources used). The decision made at the data evaluation meeting was to find out if the data collected by the county of Norrbotten should be used instead of some parts of the historical data base and previously used assessment input data. Based on discussions with Thomas Hasselborg, a former employer at the county board, and who has worked with the vendace fishery for a long time and Enderlein (1986), we decided to use the county board “Fiskenämnden” data. Thus, the final time series of catch used for the new assessment is presented in Figure 15. It includes catches of vendace in trawls based on data from the historical data base 1914 – 1960 (Data 1), fiskenämnden and official catch statistics from FiV/SWAM 1961 – 2002 (Data 2) and official catch statistics (Data 2), corrected for catches of other species 2003-2020 (Data 4). Catches of vendace by other gear are estimated from data from fiskenämnden 1961 – 1993 and official catch statistics provided by FiV/SWAM (Data 2). Trawl catches and catches with other gear are added to form one single series of total catch (Figure 15).

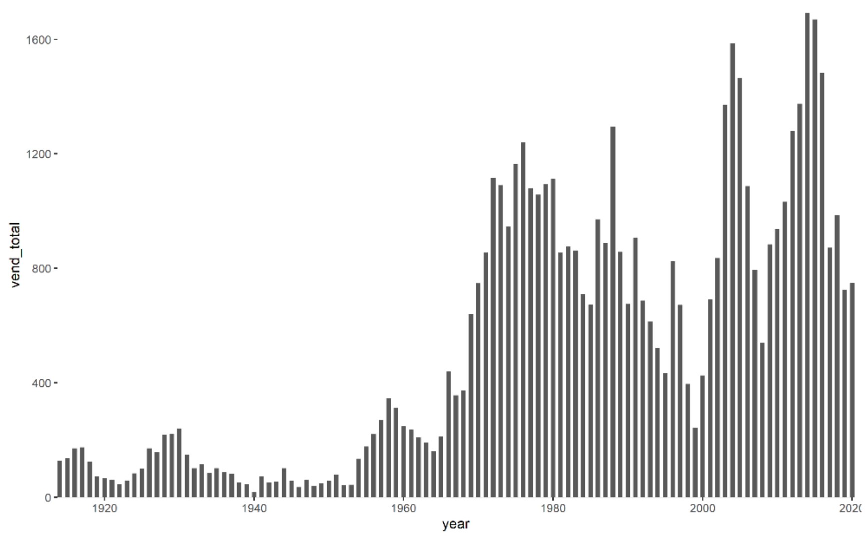

Figure 15. Vedace catches proposed for the new vendace assessment model.

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Annex 1. Sammanställning över känd och skattad fångstsammansättning i trålfiske efter siklöja 1961-2003.

Statistik baserad på trålrapport, loggbok samt stickprov i trålfångster. Från Thomas Hasselborg

År	silö	sek silö	övrigt	total	andel silö	sek silö	antal lag	Kommentar
1961	36609							Baserad på offentlig statistik och trålfiskerapporter - Fiskenämnderna/Hasselborg
1962	108315							Baserad på offentlig statistik och trålfiskerapporter - Fiskenämnderna/Hasselborg
1963	91510	0	61895	153405	60%	okänd	22	Känd fördelning. Rapport Lst BD-län 1986-01-22
1964	110752	0	73562	184314	60%	okänd	25	Känd fördelning. Rapport Lst BD-län 1986-01-23
1965	163153	0	125271	288424	57%	okänd	31	Känd fördelning. Rapport Lst BD-län 1986-01-24
1966	294118	20259	37857	352234	89%	6%	31	Känd fördelning. Trålrapport Lst BD-län 1969-02-11
1967	247584	58411	10730	316725	97%	19%	36	Känd fördelning. Trålrapport Lst BD-län 1969-02-12
1968	290351	61429	7447	359227	98%	6%	36	Känd fördelning. Trålrapport Lst BD-län 1969-02-13
1969	507822	31413	23894	563129	96%	6%	39	Antagen fördelning baserad på 1969-års rapport
1970	431554	91431	20304	543289	96%	17%	40	Antagen fördelning baserad på 1969-års rapport
1971	490480	234000	51941	776421	93%	32%	44	Antagen fördelning baserad på 1969-års rapport
1972	860599	20456	38256	919311	96%	2%	42	Känd fördelning. Trålrapport Lst BD-län 1973-02-20
1973	787992	19385	65723	873100	92%	2%	42	Känd fördelning. Trålrapport Lst BD-län 1974-04-02
1974	586354	18000	36352	640706	94%	2%	44	Känd fördelning. Trålrapport Lst BD-län 1975-04-17
1975	741389	23137	57211	821737	93%	3%	44	Känd fördelning. Trålrapport Lst BD-län 1976-03-29
1976	755717	31870	87906	875493	90%	4%	44	Känd fördelning. Trålrapport Lst BD-län 1977-01-19
1977	714702	24345	154556	893603	83%	3%	44	Känd fördelning. Trålrapport Lst BD-län 1978-03-24
1978	712771	14255	227273	954299	76%	2%	39	Rapport 1986. Skattad andel sek silö efter 3 stickprov.
1979	702000	133380	202620	1038000	80%	11%	39	Rapport 1986. Skattad andel sek silö efter 2 stickprov
1980	866040	17320	263207	1146567	77%	2%	39	Rapport 1986. Skattad andel sek silö efter 4 stickprov
1981	655000		70000	725000	90%	okänd	38	Känd fördelning. Rapport Lst BD-län 1986-01-22

1982	677000		90000	767000	88%	okänd	40	Känd fördelning. Rapport Lst BD-län 1986-01-23
1983	662000		60000	722000	92%	okänd	39	Känd fördelning. Rapport Lst BD-län 1986-01-24
1984	544000	16320	33680	594000	94%	3%	36	Rapport 1986. Skattad andel sek silö efter 1 stickprov
1985	665814		198879	864693	77%	0%		Rapport 1986. Skattad andel sek silö efter 1 stickprov
1986	926502		138443	1064945	87%	0%		Loggbok. Skattad andel sek silö efter 1 stickprov
1987	813197		242903	1056100	77%	0%		Loggbok. Skattad andel sek silö efter 1 stickprov
1988	1271414	12714	345890	1630018	79%	10%		Loggbok. Skattad andel sek silö efter 3 stickprov
1989	807837		538558	1346395	60%	okänd		Loggbok
1990	942683		628455	1571138	60%	okänd		Loggbok
1991	749875	82486	697996	1530357.3	54%	10%		Loggbok. Skattad andel sek silö och övrig efter 1 stickprov
1992	644234		429489	1073723	60%	0%		Loggbok. Skattad andel sek silö och övrig efter 3 stickprov
1993	503684	56316	424840	984840	57%	10%	34	Loggbok. Skattad andel sek silö och övrig efter 28 stickprov
1994	328320	127680	494520	950520	48%	28%	32	Loggbok. Skattad andel sek silö och övrig efter 49 stickprov
1995	307996	72245	0	380241	34%	19%	30	Loggbok. Fångst just för 7 lag, 253 ton skattad till 88,1 ton siklöja
1996	725500	50785	496522	1272807	61%	7%	29	Loggbok 625 ton för 50 fiskare. Totalfångst skattad till 725 ton för samtliga 58 fiskande 1996
1997	598000		371200	969200	62%	okänd	28	Loggbok 598 ton av 58 fiskare. Fångsten behövs inte justeras
1998	372633		88410	461043	81%	okänd	27	Loggbok antas svara för den verkliga fångsten ingen justering
1999	112210	109004	272016	493230	45%	22%	19	Loggboken redovisar 345302 kg siklöja och 145328 kg strömming samt 2600 kg sik. Fångsten justerad efter art och kön enligt stickprover 1999. Av 48 tillstånd nyttjades 19 st under året.
2000	329129	67411	253526	650066	61%	10%	19	Loggbok redovisar 533339 kg siklöja (82 %) och 116727 kg övrig fisk. Fördelning av total fångst enligt provtagning
2001	483057	182310	37633	703000	69%	26%	20	Loggbnok redovisar 665 ton siklöja ( ) och 29,4 ton övrig fisk. Fördelning av arter enl fivs provtagning baserat på total fångst
2002	649162	140573	335265	1125000	58%	13%	20	Loggbnok redovisar 969 ton siklöja ( ) och 154 ton övrig fisk. Fördelning av arter enl fivs provtagning baserat på total fångst
2003	1188946	310355	80198	1579499	75%	20%	20	Loggbnok redovisar 1499 ton siklöja ( ) och 59 ton övrig fisk. Fördelning av arter enl fivs provtagning baserat på total fångst
Medel	593002	67576	192059	834507			34	

FISKERIVERKET
Utredningskontoret i Luleå

Statistik om det Norrbottniska siklöjfisket

Trålfisket

Siklöjan fångas i huvudsak med trål. Trålfisket startades på försök i början av 1960-talet och permanentades 1992. Fångsten har stadigt ökat till en nivå av 1 000 till 1 500 ton siklöja per år. För närvarande innehar 66 fiskare (33 lag) tillstånd att bedriva trålfiske, fördelade över Norrbottenskusten från Haparanda i nordost till Umeå i syd.

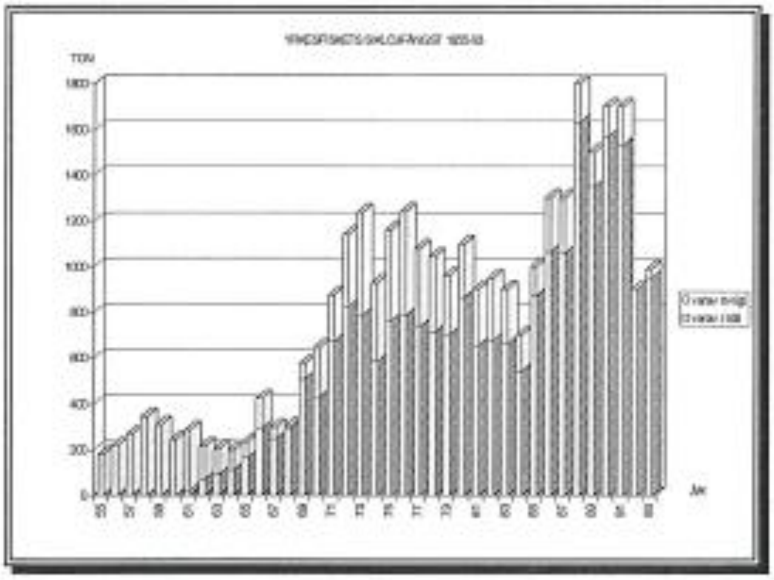
Fisket bedrivs med s.k. partrålning vilket innebär att två båtar tillsammans släpar redskapet. Trålfisket regleras genom tidsbegränsning och tillståndsgivning och handläggs av Fiskeriverket. I skärgården är fiske tillåtet 20 september till 31 oktober.

Övrigt fiske

Fångsten av siklöja från annat fiske domineras av vinternotfiske under januari-april. Något egentligt fiske med skötar och siklöjryssjor förekommer inte i det yrkesmässiga fisket efter siklöja.

Fritidsfisket

Fritidsfisket efter siklöja har starka traditioner längs Bottenvikskusten. Fisket bedrivs uteslutande med skötar och nät under september-oktober. Officiell statistik om fritidsfiskets fångst saknas men torde motsvara 10-12 % av yrkesfiskets totala fångst.



Figuren beskriver siklöjfiskets utveckling med trål och övriga redskap åren 1955-93.

Annex 2. Sampling protocol for the self-sampling program.

Fångst per tråldrag (ifylles på sjön)

Provtagning (ifylles efter landning)

(Fångsten skall inte delas på båtar, endast en i varje lag behöver bokföra)

Obs! Om provet skall kunna användas som underlag för loggbokens landningsdeklaration måste provet sorteras och artfördelas innan fångsten bortforslats från landningsplatsen

Fartyg i trållaget:

År 2021 **Datum**	**Fångstområde** **N (lat.)**	**E (long.)**	**Totalfångst per tråldrag i kg**	**Tråltid antal timmar**	**Loggboks-blad nr**	**Prov (0,1kg)** **Provets totalvikt**	**Siklöja >12,5 cm**	**Siklöja (juv) <=12,5 cm**	**Strömming**	**Sik**	**Övriga arter**	**Anmärkning**
Datum skrivs som mmdd.T. ex 24 september blir 0924	Fångstområdet anges i grader och min. Om fisket skett i flera rutor anges den ruta där trålen sätts. N är nordlig och E är ostlig koordinat.		Total fångstvikt i kg för alla arter. Varje tråldrag i sin helhet redovisas på en egen rad. Skattningarna baseras på fyllnadsgrad i bingen.	En hink på 10 l tas ur den mest fyllda bingen före landning av fångsten. Provet kan vägas och sorteras på arter i samband med landning. Alla vikter anges i 0.1 kg. OBS! Provet behöver inte väga exakt 10kg. Fisk skall således inte tas bort eller läggas till hinken. I stället vägs hela provet. Siklöja större än 12,5 cm och siklöja mindre än 12,5 cm (juveniler) vägs och redovisas skilt. Strömming och sik redovisas separat. Andra arter anges i klump. Vill man notera stor förekomst av någon särskild art kan man skriva i anmärkningsfältet. Det blir bara en rad per dag för provtagning då provet skall tas på hela dagsfångsten, men kanske flera rader per dag för fångst per tråldrag varför det är viktigt att data från provtagningen hamnar på rätt datum(=rad). Den skattade totalvikten siklöja (=andel siklöja*totalfångst) och ev andra arter införs i loggbokens landningsdeklaration.								Här görs anmärkningar om selektionsmetod och annat som behövs noteras, t ex styrgruppsbeslut.

Annex 3. List of gear codes (SWE)

ACTIVE /PASSIVE	KOD	REDSKAP
?	1	Annat redskap
A	210	Landvad, not
A	221	Snurrevad dansk
A	311	Parbottentrål siklöja
A	312	Bottentrål torsk selektionspanel Bacoma
A	313	Bomtrål
A	314	Bottentrål Sill / skarpsill
P	721	Sillgarn/strömmingsskötar
P	724	Siknät
P	726	Siklöjenät/skötar
P	812	Kilnot
P	827	Gäddryssjor
P	831	Sik/Lax ryssjor
P	832	Sill/strömmingsryssja
P	841	Kombifällor (bottensatta)
P	845	Laxfälla (Push-up)

Annex 4. Final catch data used and their sources

Catches (Data 1-4)

	data from historic database SLU Aqua (Data 1)
	data from the county board "fiskerinämnden " (Data 2)
	estimated discussions with T. Hasselborg and from figure in annex 1
	average of the year 1992 and 1994
	official catch statistics separate send out from SWAM (Data 2)
	official catch statistics yearly provided by SWAM (Data 2)
	official catch statistics yearly provided by SWAM as total and corrected for pure vendace from the self sampling program (provblanketter) (Data 2 and 4)

year	vendace trawl	vendace other gear	vendace total catch in assessment
1914	128.59	NA	128.59
1915	136.48	NA	136.48
1916	170.67	NA	170.67
1917	174.33	NA	174.33
1918	123.94	NA	123.94
1919	72.61	NA	72.61
1920	66.64	NA	66.64
1921	59.36	NA	59.36
1922	45.87	NA	45.87
1923	58.02	NA	58.02
1924	82.78	NA	82.78
1925	99.93	NA	99.93
1926	171.08	NA	171.08
1927	157.32	NA	157.32
1928	217.72	NA	217.72
1929	221.63	NA	221.63
1930	240.71	NA	240.71
1931	148.22	NA	148.22
1932	100.87	NA	100.87
1933	114.84	NA	114.84
1934	83.84	NA	83.84
1935	101.21	NA	101.21
1936	88.8	NA	88.8
1937	81.24	NA	81.24
1938	51.52	NA	51.52
1939	44.51	NA	44.51
1940	18.96	NA	18.96
1941	73.64	NA	73.64
1942	52.28	NA	52.28
1943	54.65	NA	54.65
1944	101.88	NA	101.88
1945	57.94	NA	57.94
1946	34.55	NA	34.55
1947	61.05	NA	61.05
1948	39.65	NA	39.65
1949	48	NA	48

1950	57	NA	57
1951	78	NA	78
1952	43	NA	43
1953	44	NA	44
1954	135	NA	135
1955	177	NA	177
1956	220	NA	220
1957	269	NA	269
1958	346	NA	346
1959	312	NA	312
1960	248	NA	248
1961	36.609	200	236.609
1962	108.315	100	208.315
1963	91.51	100	191.51
1964	110.752	50	160.752
1965	163.153	50	213.153
1966	314.377	125	439.377
1967	305.995	50	355.995
1968	351.78	20	371.78
1969	539.235	100	639.235
1970	522.985	225	747.985
1971	724.48	130.717	855.197
1972	881.055	234.85	1115.905
1973	807.377	282.7	1090.077
1974	604.354	342	946.354
1975	764.526	399.5	1164.026
1976	787.587	453.9	1241.487
1977	739.047	339.9	1078.947
1978	727.026	330	1057.026
1979	835.38	258.4	1093.78
1980	883.36	230.8	1114.16
1981	655	200	855
1982	677	200	877
1983	662	200	862
1984	560.32	150	710.32
1985	665.814	6.487	672.301
1986	926.502	44.849	971.351
1987	813.197	74.6	887.797
1988	1284.128	11.55	1295.678
1989	807.837	48.664	856.501
1990	628.4552	46.069	674.5242
1991	832.3613	73.972	906.3333
1992	644.2338	42.569	686.8028
1993	560	53.7655	613.7655
1994	456	64.962	520.962
1995	380.241	53.0125	433.2535
1996	776.285	48.491	824.776
1997	598	73.762	671.762
1998	372.633	23.2095	395.8425
1999	221.214	21.5335	242.7475
2000	396.54	28.8952	425.4352
2001	665.367	26.2045	691.5715
2002	789.735	45.501	835.236
2003	1283.359	88.0905	1371.45

2004	1500.485	85.186	1585.671
2005	1396.473	68.5565	1465.03
2006	1024.052	63.149	1087.201
2007	758.6838	36.3777	795.0615
2008	499.3019	39.8	539.1019
2009	850.9528	32.664	883.6168
2010	899.2636	38.388	937.6516
2011	981.5631	50.776	1032.339
2012	1214.547	65.146	1279.693
2013	1280.582	93.9324	1374.515
2014	1616.056	76.289	1692.345
2015	1594.413	74.3645	1668.778
2016	1426.813	56.631	1483.444
2017	840.6721	30.776	871.4481
2018	948.4743	36.6715	985.1458
2019	696.426	28.4755	724.9015
2020	730.9742	18.973	749.9472

Vendace benchmark 2021. WD2: Vendace life history analyses

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Background - Sampling design for the vendace pair bottom trawl fishery

The sampling from the trawl fishery for vendace is carried out during the fisheries five active weeks in September-October. Sampling from the catches is done from fifteen randomly selected fishing trips and boat pairs. These fifteen trips are divided in three periods, with five samples from five fishing areas during the first, third and fifth week of this period.

The catches are landed unsorted and therefore, the subsampling can take place on the landed catch, whereas it gives a representative picture of the species composition in the total catch. From each fishing trip, date, coordinates, effort data in number of trawl hours, total catch volume and the logbook page number is noted on a protocol.

At each fishing trip, a random subsample (about 10 liters) is taken from the unsorted landed catch for estimation of the total catch composition in terms of size and weight. The sample must include at least 100 individuals of the most common species. All fish species in the subsample are measured by length and number per cm class is recorded. For vendace, length measurements are also separated by gender (juveniles, females, males). Total weight is given per fish species. The results are reported per species on a length measurement protocol. See also WD1 *Catch statistics and associated sampling.*

From each subsample, vendace individuals are also collected for biological analysis. Biological data such as length, weight, sex, maturity (4 grade scale) and otoliths for age determination are collected from each fish. The sampling is carried out by staff from the County Administrative Board in Norrbotten, and the age determination, data entry and archiving of data and otoliths is done by staff from SLU Aqua.

Summary of data available for vendace life history parameter analyses

In total, 103396 vendace individuals were classified into cm size classes during the years 1997 to 2020 (Table 1, A1). Across the years 2001 to 2020, 12495 individuals were aged out of the 18740 fish that were collected for biological analysis from the commercial vendace fishery (Table 1, A2). From the survey data, 7489 out of 7496 individuals were aged, across the years 2009-2020 (Table 1, A3). Data from the commercial fishery was collected from five main fishing areas (Fig. A1) during five weeks in September to October (see section *Sampling design – vendace pair bottom trawl fishery*).

Table 1: Number of samples available for life history analyses, by year. LF denotes length frequency (size class) classification, Biological analysis denote individuals where age, length, sex and maturity were measured.

	Commercial			Survey	
	LF	Biological analysis			
Year	**length**	**age**	**length**	**age**	**length**
1997	852				
1998	2532				
1999	7655				
2000	6783				
2001	9439	1025	1026		
2002	3585	559	1065		
2003	3800	595	810		
2004	1981	385	386		
2005	864	449	450		
2006	1472	498	1024		
2007	1197	502	1900		
2008	4089	496	500		
2009	8895	498	1900	369	369
2010	8646	502	502	664	664
2011	6932	504	505	746	747
2012	5174	499	1000	765	765
2013	4280	556	870	849	853
2014	2068	650	654	738	739
2015	4122	1038	1040		
2016	4383	501	980	68	68
2017	4573	552	1067	697	697
2018	2780	693	1050	897	898
2019	4145	989	1001	880	880
2020	3149	1004	1010	816	816
Total	**103396**	**12495**	**18740**	**7489**	**7496**

Mean length

We find a general pattern of a small increase in mean length over time during the years 2000 to 2020 (Fig. 1) in the commercial data. For the full data set, including both northern and southern samples, vendace mean length increased, on average, by 0.4 mm per year (Fig. 1, upper panel). When separating the data into northern and southern areas, we note that the increase in length is larger in the north (0.6 mm/year) compared to the south (0.2 mm/year) (Fig. 1, lower panel).

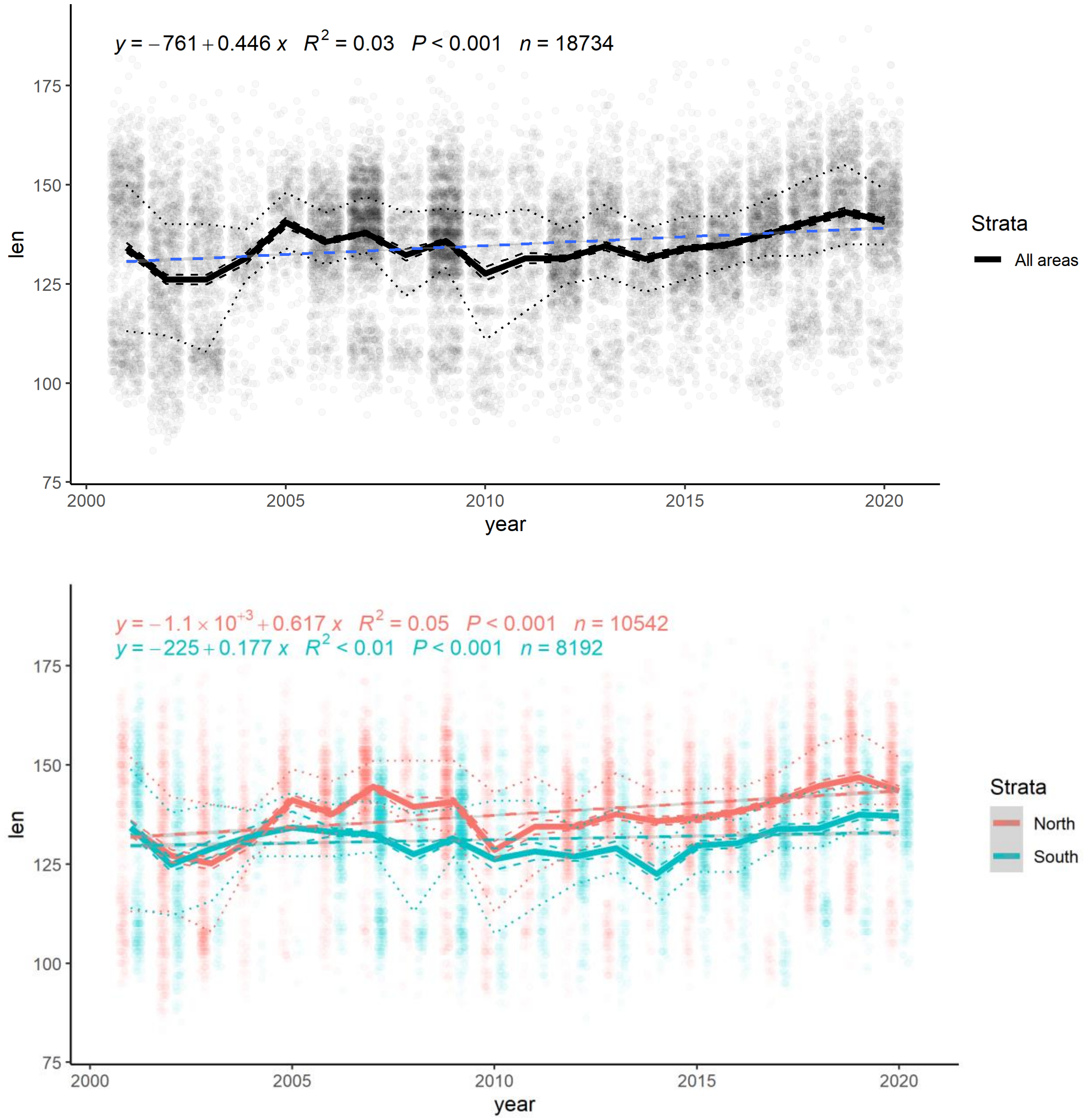

Figure 1: Mean (solid line) length over time, with +-95% CIs (dashed lines), and first and third quartiles (dotted lines), for all (upper panel) and northern (red, lower panel) and southern (blue, lower panels) areas, respectively. Straight dashed lines snow the best fit OLS linear regression models, with +-95% confidence bands shaded in grey. Semi-transparent dots show the raw data.

Life History parameter estimation

We found no patterns of sexual length dimorphism in the data (Fig. A2). Length at age data revealed a potential difference in growth patterns across the northern and southern fishing areas (Fig. 2), in line with the mean length increase shown in Fig. 1 above. This was confirmed by a forward selection approach when evaluating the relative likelihood of candidate models which include or do not include area as an explanatory factor (Table A2; see section *Length frequency distributions (LFDs) and Age-length-keys (ALKs)* below for details). Thus, we performed the following growth analyses on combined sexes, separating the data into the "north" and "south" fishing areas.

Von Bertalanffy growth parameters

Four different VB curves were fitted based on the north-south data (Fig. A3) using Nonlinear Least Squares models (*nls* in R) to test for possible differences in growth between the areas. At all ages +0.5 years were added to all age-classes as both fishery dependent and independent sampling are conducted only in autumn (Sep-Nov).

The curves (Fig. 3) reveal high k values ranging from 0.81 of the commercial South to 0.93 survey North area. In both commercial and survey data, North area L_{inf} is higher than the South. t_0 values are slightly negative, perhaps due to the lack of 'real' 0 ages, suggesting not to use this value in the assessment. CIs are very small for all the parameters (Fig. 3).

We used a Kimura likelihood ratio test (Kimura 1980) to examine the difference between the 4 VB curves (North vs South, both for commercial and survey data). The model fitting and the Kimura test were conducted by using *growthlrt()* function in R Package *fishmethods*. There are four hypothesis tests in the Kimura test: H0 vs. H1, H0 vs. H2, H0 vs. H3, and H0 vs. H4 (Table A5). All tests were rejected ($p < 0.001$; Table A5), thus the VB curves are considered statistically different.

We note that it is normal to observe statistically significant differences within sub-areas of the same stock (e.g. North-South). We do however not consider the difference found here in the VB growth curves to be large enough (Fig. 3) to justify an area based assessment model with the use of two different growth patterns.

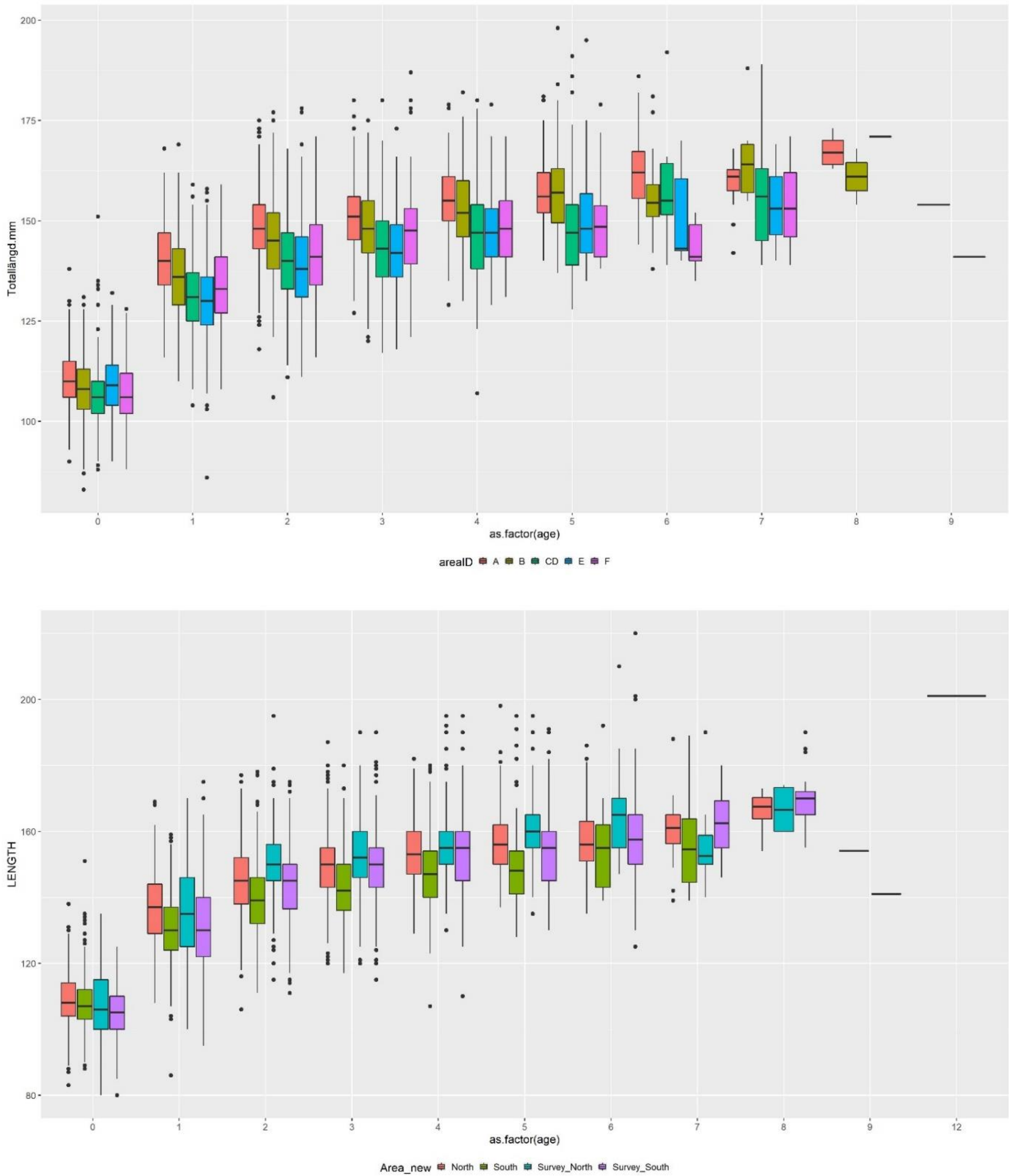

Figure 2: Commercial (upper panel), and survey together with commercial (lower panel) length at age relationships, separated into the five fishing areas (A, B, CD, E, F; upper panel) or into north (area A+B+F) and south (area CD+E) (lower panel).

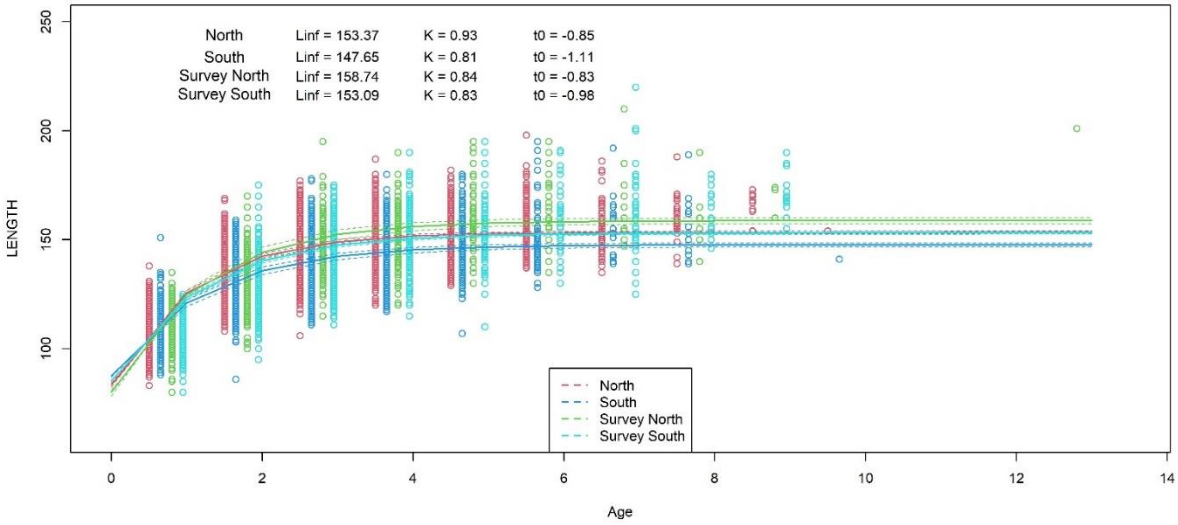

Figure 3: VB growth curves (solid lines) for the commercial (North, South) and survey (Survey North, Survey South) data, with 95% confidence bands (dashed lines).

Biphasic von Bertalanffy growth relationships

The existence of a trade-off between allocating energy between somatic growth and reproduction has been suggested (Lester et al., 2004). Reproductive effort should negatively influence growth: more energy would be allocated to somatic growth during the young years of life (i.e. immature fish), leading to fast growth, whereas after reaching sexual maturity, energy would be divided into two activities (reproductive investment and somatic growth), and the growth in size would decrease as a consequence. Hence, biphasic growth curves to correct for the absence of energetic costs linked to reproduction before sexual maturation (or the small energetic cost during the first few years after maturation) have been proposed (Day and Taylor, 1997; Lester et al., 2004; Charnov, 2008; Quince et al., 2008a, b).

In addition to the classical VB model, we therefore also consider the biphasic VB model

$$y(t)=L_{inf}(1-exp(-k(t-t_0))) \quad if\ t<t_1$$

$$y(t)=L_{inf}(1-exp(-k_0(t_1-t_0)-k_1(t-t_1))) \quad if\ t>t_1$$

with the additional parameters t_1, k_0 and k_1, fitted to the same data as the classic VB model (Fig. 4); model parameters are all significant and visual inspection of model diagnostics suggest that model assumptions are met (Fig. 5).

Thanks to the variation of the k rate between k_0 and k_1, L_{inf} is higher in the biphasic curve compared to the classic one (182 mm vs 154 mm) providing a better match with the L_{max} data (~ 200 mm). Residual analysis reveals a better fit to the data for the biphasic curve (especially from age 5.5 on ; Fig. A4). However, age 9.5 is better estimated in the classic VB curve due to the few and doubtful (shorter length than those of previous age) records available. The biphasic VB model can easily be implemented in SS3 (Fig. A5-6).

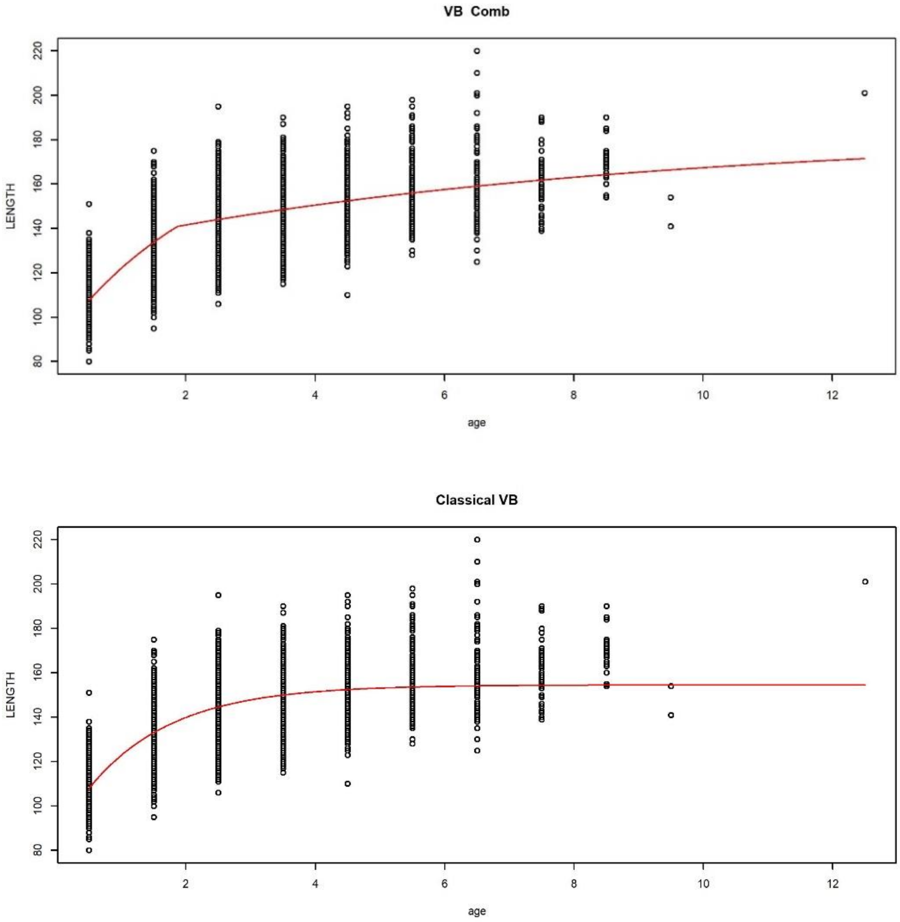

Figure 4: The biphasic (upper panel) and the classical (lower panel) VB growth models, respectively.

Biphasic Parameters:

	Estimate	*Std. Error*	*t value*	*Pr(>|t|)*
Linf	*183*	*9.227*	*19.82*	*< 2e-16 ****
k0	*0.42*	*0.065*	*6.544*	*9.23e-07 ****
t0	*-1.57*	*0.149*	*-10.49*	*< 2e-16 ****
k1	*0.012*	*0.034*	*3.49*	*0.00366 ***
t1	*1.86*	*0.022*	*84.52*	*< 2e-16 ****

t-based confidence interval:

	2.5%	*97.5%*
Linf	*164.85*	*201.03*
k0	*0.29*	*0.55*
t0	*-1.86*	*-1.27*
k1	*0.05*	*0.18*
t1	*1.82*	*1.90*

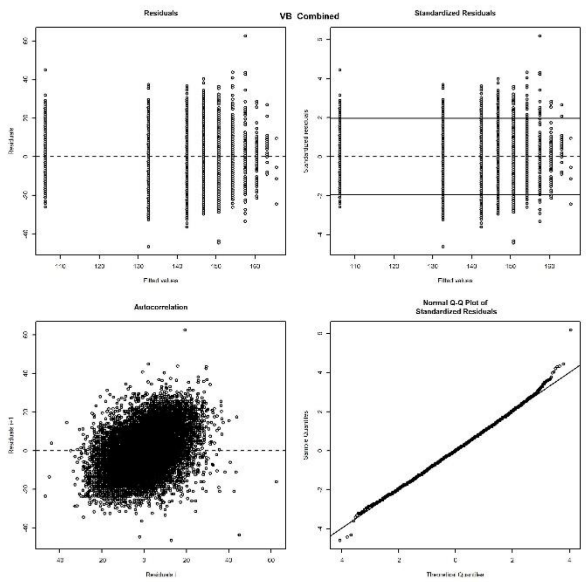

Figure 5: Biphasic VB growth model coefficients and visual model diagnostics.

Maturity ogives – length based

Length frequency distributions (LFDs) of data containing maturity stage information (Fig. A7) reveal a better representation of the smaller individuals in the survey data. The survey data was therefore used for length based maturity ogive estimation.

All-years-combined L_{50} estimation using a binomial GLM reveals no important difference between sex (Fig. 6, upper panels; females 117 mm, males 113 mm). L_{50} for sexes combined (taking into consideration also immature individuals) is 119 mm (Fig. 6, lower panel). In conclusion, L_{50} can be set to 11-12 cm.

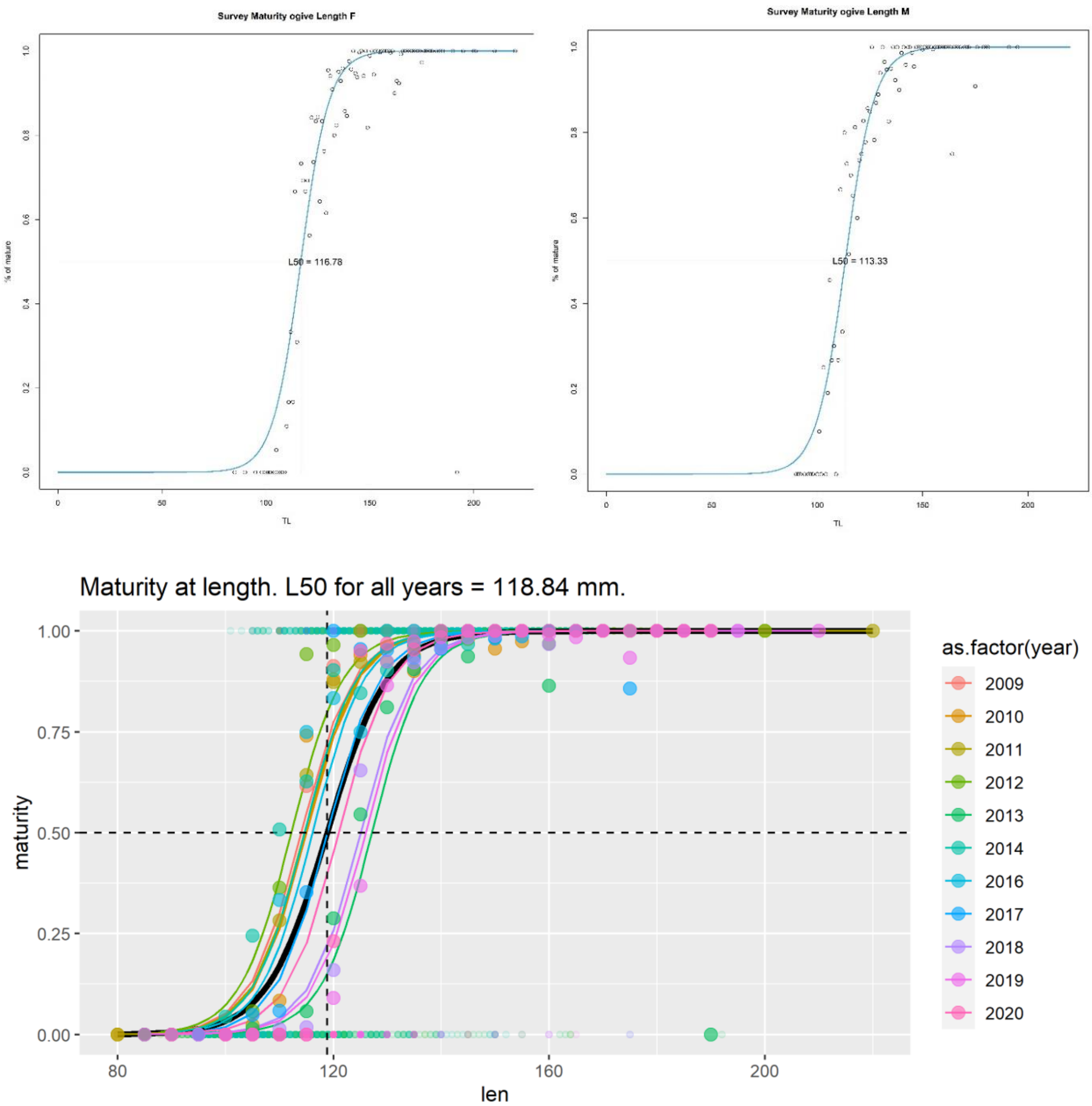

Figure 6: A binomial GLM model fit to survey female (left upper panel) and male (right upper panel) only maturity ogive lengths. Lower panel show males and females together, with yearly models and data (denoted by colour) and the full model for all years (black line). L_{50} is estimated to the lengths were 50% of individuals are mature.

Maturity ogives – age based

As for the LFDs, age distribution data containing maturity stage information (Fig. A8) reveal a better representation of the younger individuals in the survey data. Survey data will therefore be used for calculation of age based maturity ogives.

All-years-combined Age_{50} estimation using a binomial GLM reveals no important difference between sex (Fig. 7, upper panels; females 1 year, males 0.8 years). Age_{50} for sexes combined (taking into consideration also immature individuals) is 1.09 years. In conclusion, Age_{50} can be set close to one year.

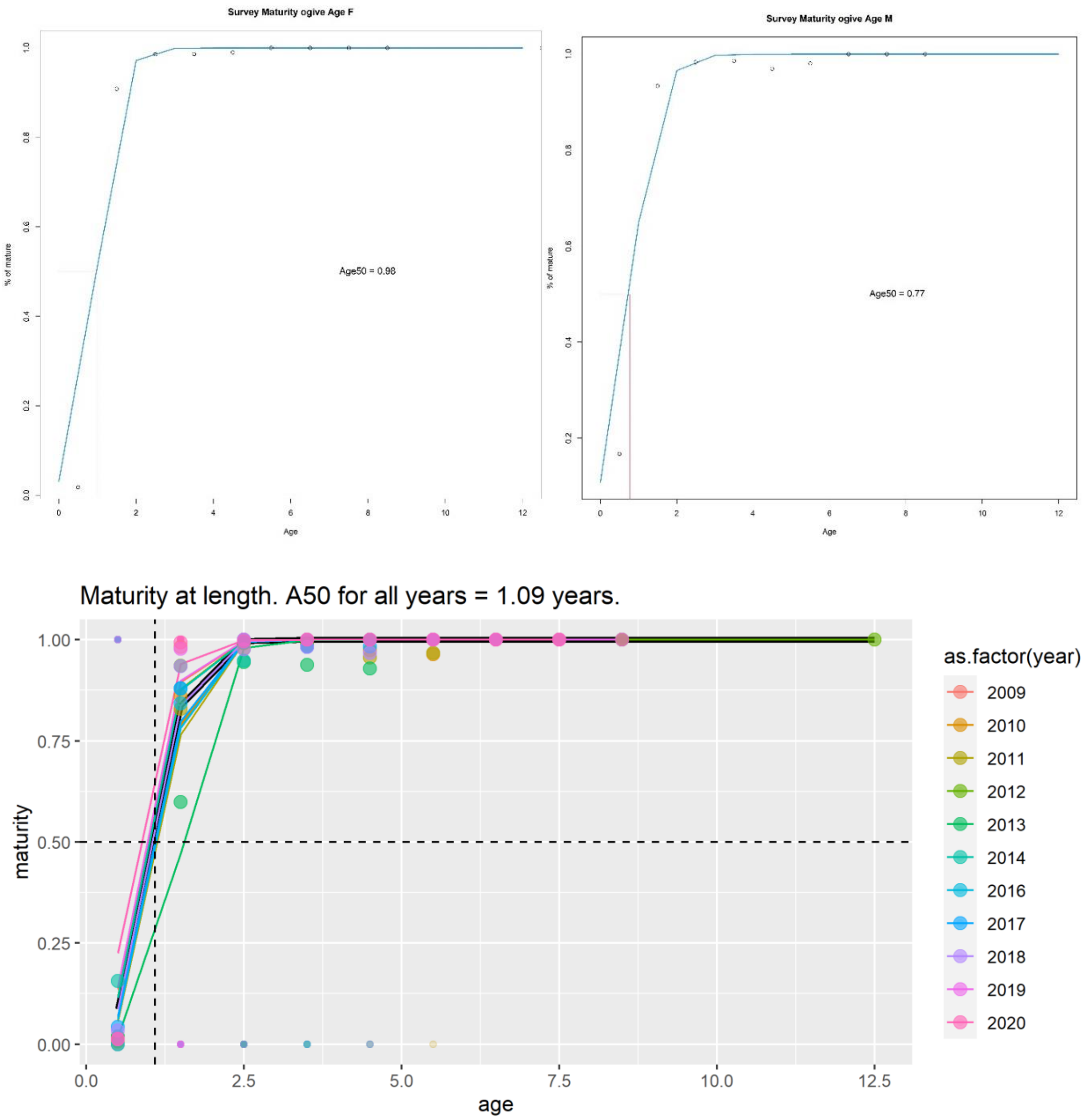

Figure 7: A binomial GLM model fit to survey female (left upper panel) and male (right upper panel) only maturity ogive ages. Lower panel show males and females together, with yearly models and data (denoted by colour) and the full model for all years (black line). Age_{50} is estimated to the lengths were 50% of individuals are mature.

Natural mortality

The natural mortality rate (M) of fish populations is one of the most important parameters for population dynamics and stock assessment models. Unfortunately, it is also one of the most difficult parameters to estimate. For this benchmark assessment a pool of methodologies can be considered to assess the impact of M on the assessment. Moreover, in this particular case, the natural mortality has to be divided in two fractions because of the seals predation. The Stock Synthesis assessment model can deal with these two types of sources of mortality separately. From now on we will refer to background mortality, or M1, as the non-seal mortality.

The Barefoot Ecologist's Toolbox (http://barefootecologist.com.au/shiny_m) can be used to derive different values of single M1 or to derive composite M1 values weighting different methods. This toolbox, developed by Jason Cope, provides a straightforward method for obtaining the estimated value of natural mortality from a range of life-history based methods (different life-history input requirement).

In the Table A6, a summary of the input and output of all methods considered in the Toolbox divided by different input requirements (Input Categories). As pointed out in the growth section, the classical VB curve does not seem to be the best way to describe the growth pattern of this species. The different growth phases showed for vendace (fast growing pattern in the first part of the curve and then a slow growth for older ages) returns distorted Classical VB parameters for the study of natural mortality. We consider the M1 values of the methodologies that use these inputs not plausible, and for this reason, these methods have been eliminated from the analyses.

Based on the assumption that A_{max} (maximum age) is the best information to be used, when available, for the final calculation of natural mortality (Then et al. 2015), the final derived composite M1 (Fig. 8) was calculated using the methodologies named *Then_nls*, *Then_lm* and *Hamel_Amax* (Table A6).

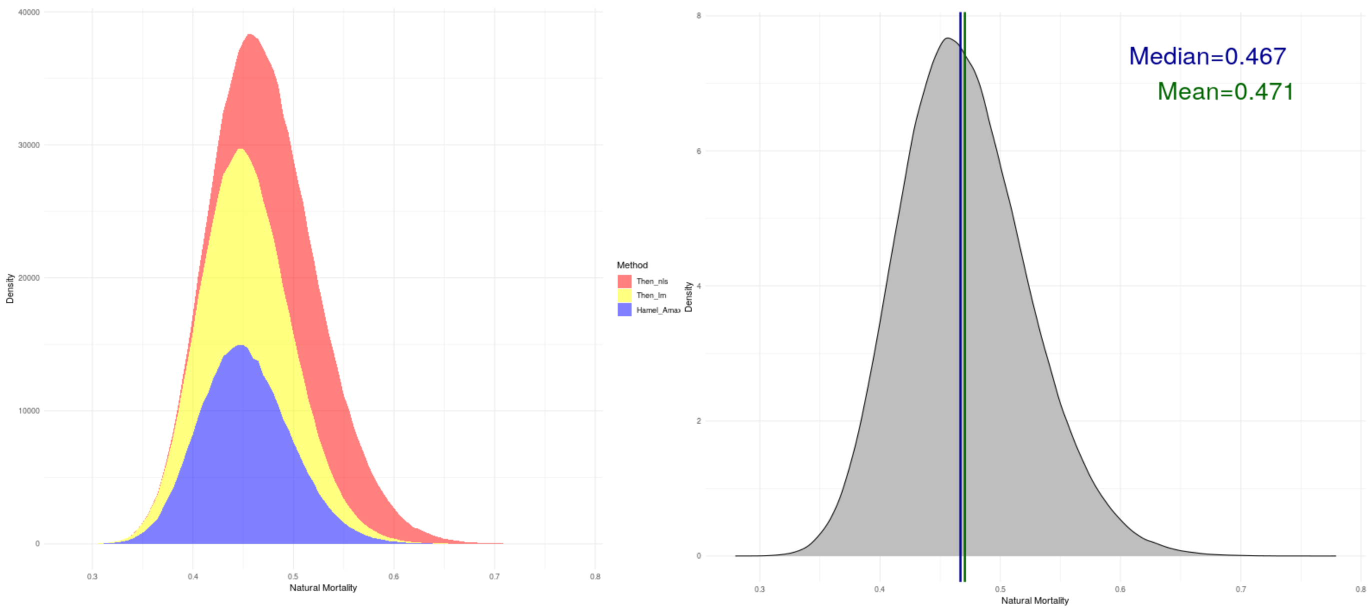

Figure 8: Estimates for the M1 from the three final methods separately (left) and the final composite M1 weighting the estimates together (right).

To represent structural uncertainty around background natural mortality, three plausible set of M1's have been selected to be tested in the assessment. Last year's assessment M will be used as the lower limit for M1 while the composite M1 described above as the upper limit (values are taken as value at maximum age and scaled by the body size-at-age of the fish with Lorenzen option within SS3). In the between, a middle value based on averaged of the two vectors (Fig. A9). The three M1s will be treated as alternative hypothesis in the context of the ensemble approach (M1 as one dimension of the ensemble grid).

Length frequency distributions (LFDs) and Age-length-keys (ALKs)

LFDs from the length-classified data show that fish from the northern areas are slightly larger than from the south (Fig. 9), whereas fish caught in September or October has approximately the same length (Fig. 10).

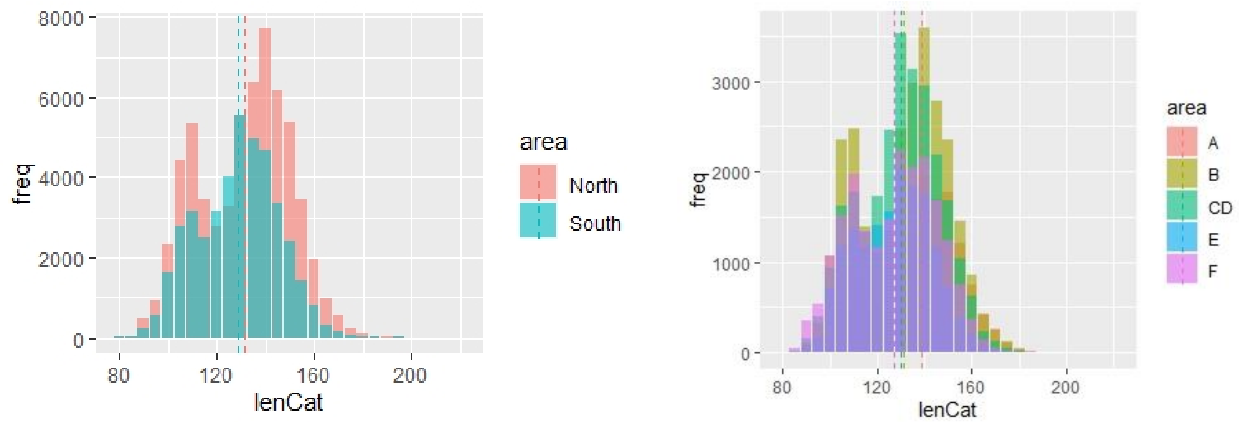

Figure 9: LFDs for years 1997-2020 from the length-classified data lumped together, stratified in to northern and southern (left panel) or areas A, B, CD, E and F (right panel). Dashed vertical lines show mean lengths weighted by number of individuals in each length class.

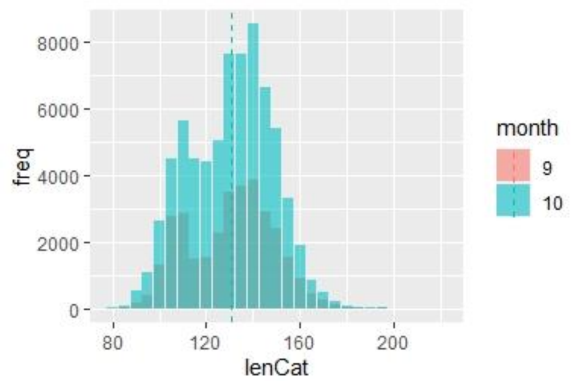

Figure 10: LFDs for years 1997-2020 from the length-classified data lumped together, stratified in to fish caught in September (9) or October (10). Dashed vertical lines show mean lengths weighted by number of individuals in each length class.

When separating LDFs across years, the length difference between areas is still visible, and a difference across months also becomes apparent for some years (Fig. A10-11).

We investigated the importance of the timing (month of the year) and the area (A-F, North, South; Fig. A1) of the fishing trips for estimation of age-length relationships and calculations of yearly fishery dependent and independent ALKs and LFDs, by using a candidate model forward selection approach (see e.g. Gerritsen et al 2006, ICES JMS) that evaluates the relative likelihood of a set of candidate models. A multinomial logistic regression base model (package *multinom* in R) without any explanatory factors was compared with candidate models where month and/or year was taken into account, using AICc as the selection critera (Tab. A4). The candidate model including fishing month of the year and area as explanatory variables was found to be the best (having the lowest AICc-value) model describing age as a function of length, for both commercial and survey data, although differences in McFaddens pseudo r^2 were not large. As with the VB growth curves, we do not consider the differences large enough to justify an area based assessment model, however a decision was taken that yearly ALKs and LFDs should be calculated taking fishing area (North/South) into account.

Figure 11 illustrates the difference across the north and south areas in combination with fishing month, for the year 2020 ALKs. Again, we here see the difference in growth, especially for smaller (younger) fish, both for the commercial and survey data. For example, the conditional probability of age-1 fish, given a length of 135-145 mm, is larger in the north compared to the south, whereas for age-2 fish, given the same length, the relationship is the opposite (Fig. 11).

To take fishing area into account when calculating yearly ALKs and LFDs, based on the commercial data, the number of individuals per length- and age-class was weighted by the proportion of total landings per area and year (Table A7). As the survey data is collected along transects distributed evenly across the fishing areas, weighting by area when calculating ALKs and LFDs based on the survey data was not deemed necessary. Figure 12 and 13 illustrates the ‘full’ commercial ALK for the year 2020 and the LFDs for years 1997-2020, respectively, weighted by the proportion landings in the north and south areas.

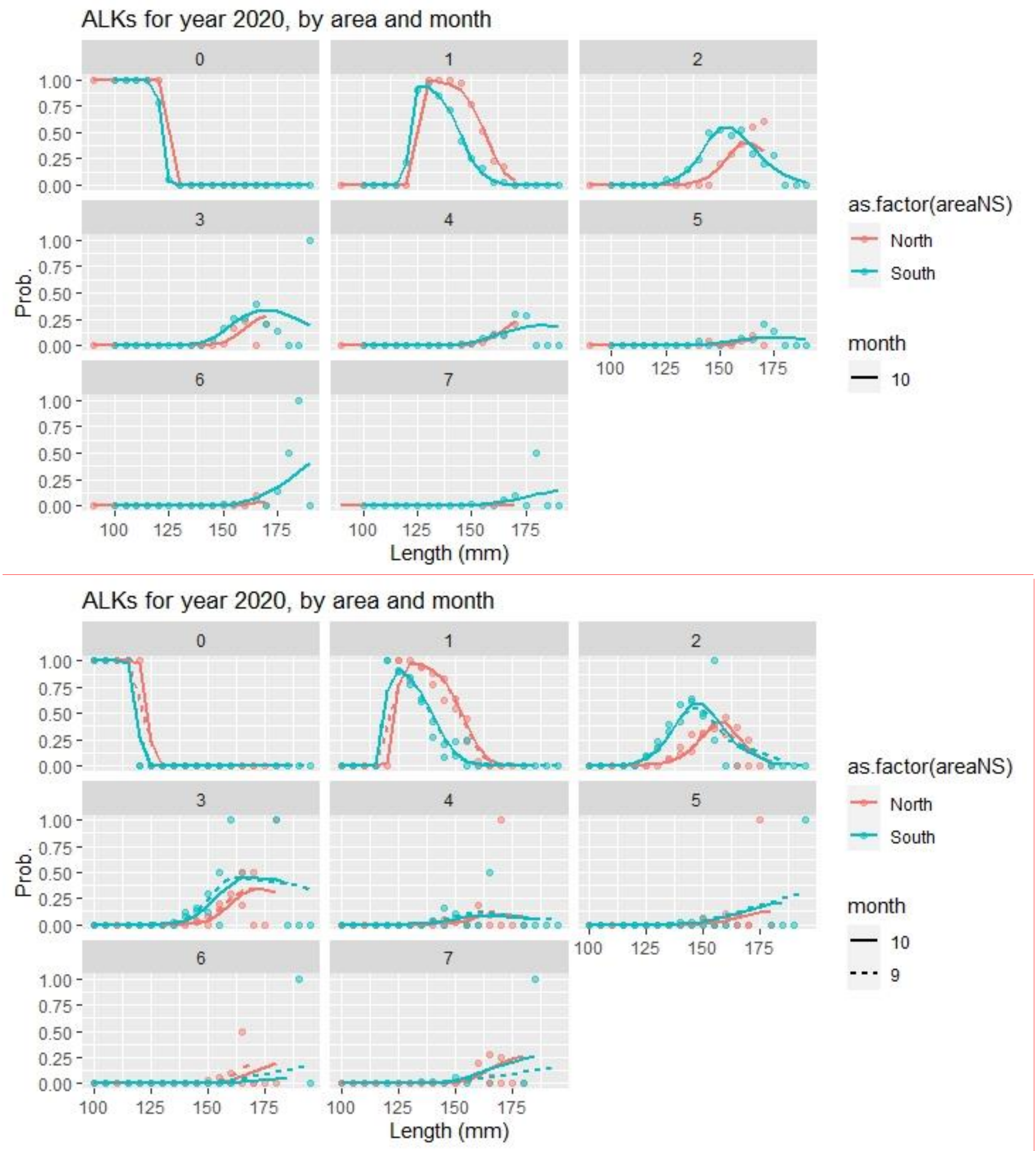

Figure 11: Age-length-keys for the year 2020, based on the commercial (lower panel) and survey (upper panel) data, by fishing area (North or South) and month (9 – Sep.; 10 – Oct.). Ages 0-7 are separated by panels. Lines show the best candidate model fitted to the data (dots). Note that the survey in 2020 was conducted in October, hence no data for September.

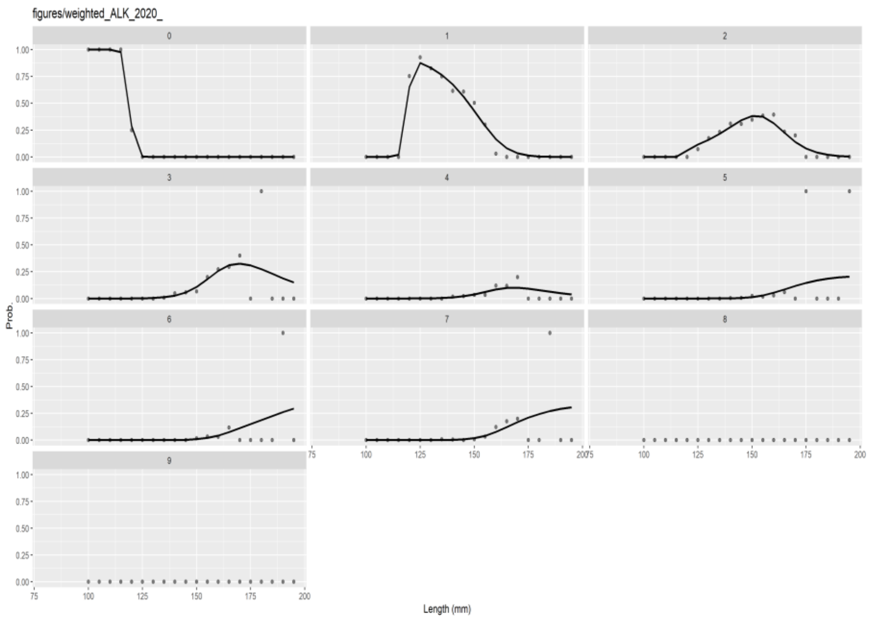

Figure 12: Age-length-key for the year 2020, based on the commercial data, weighted by the proportion landings by fishing area (North or South). Ages 0-9 are separated by panels. Lines show the best candidate model fitted to the data (dots).

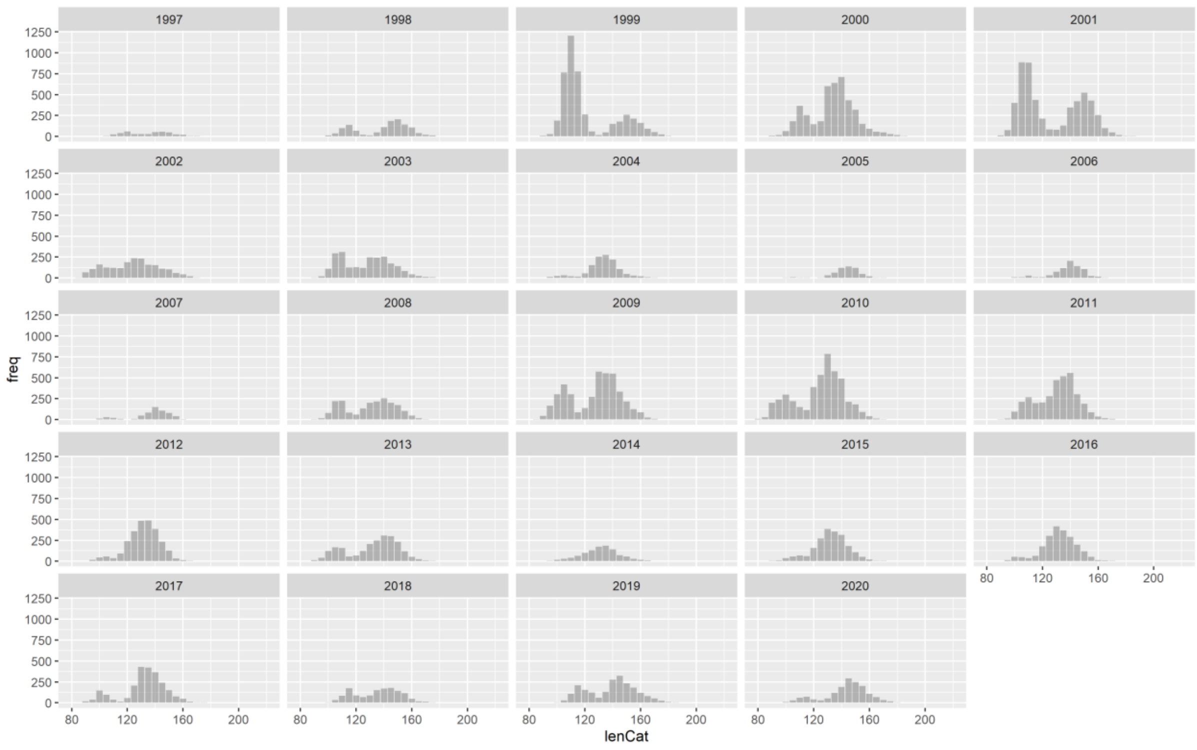

Figure 13: LFDs across years 1997-2020 from the length-classified, commercial, data, weighted by the proportion landings by fishing area (North or South).

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Vendace benchmark 2021

Supplementary figures and tables for the working document on vendace life history parameter estimation

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Supplementary figures

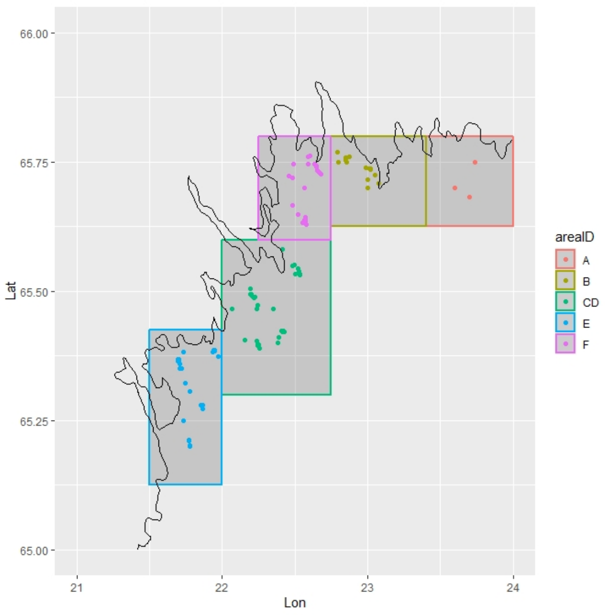


Figure A1: The five main fishing areas: A – Haparanda, B – Kalix, CD – Luleå, E – Piteå and F – Råneå. Areas are grouped into a "North" (A + B + F) and "South" (CD + E) in the analyses. Dots show (overlapping) survey sampling coordinates.

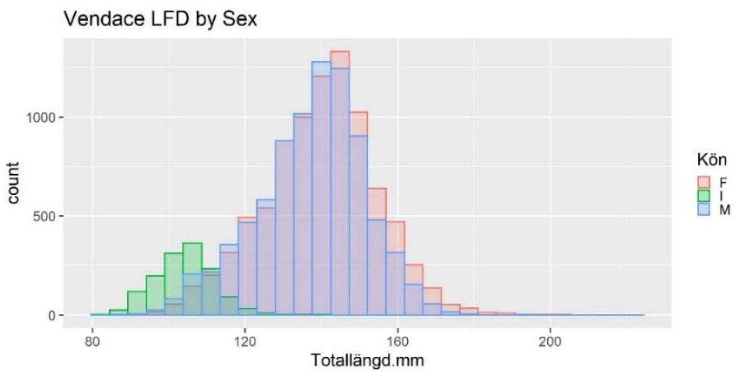


Figure A2: Vendace length frequency distribution by sex: data show no particular sexual dimorphism (commercial + survey data together). (F)emale, (I)mmature and (M)ale distributions are denoted by pink, green and blue colours. "Totallängd.mm" is length in mm.

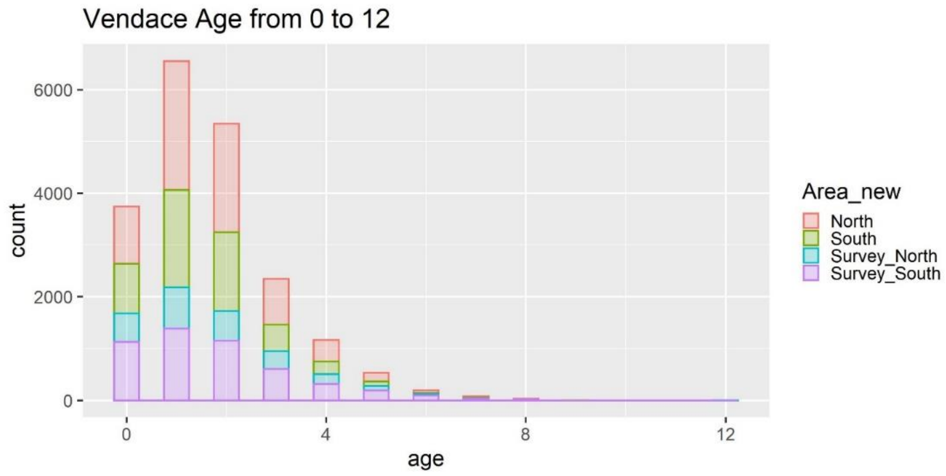


Figure A3: Age distribution of commercial and survey data, separated by area.

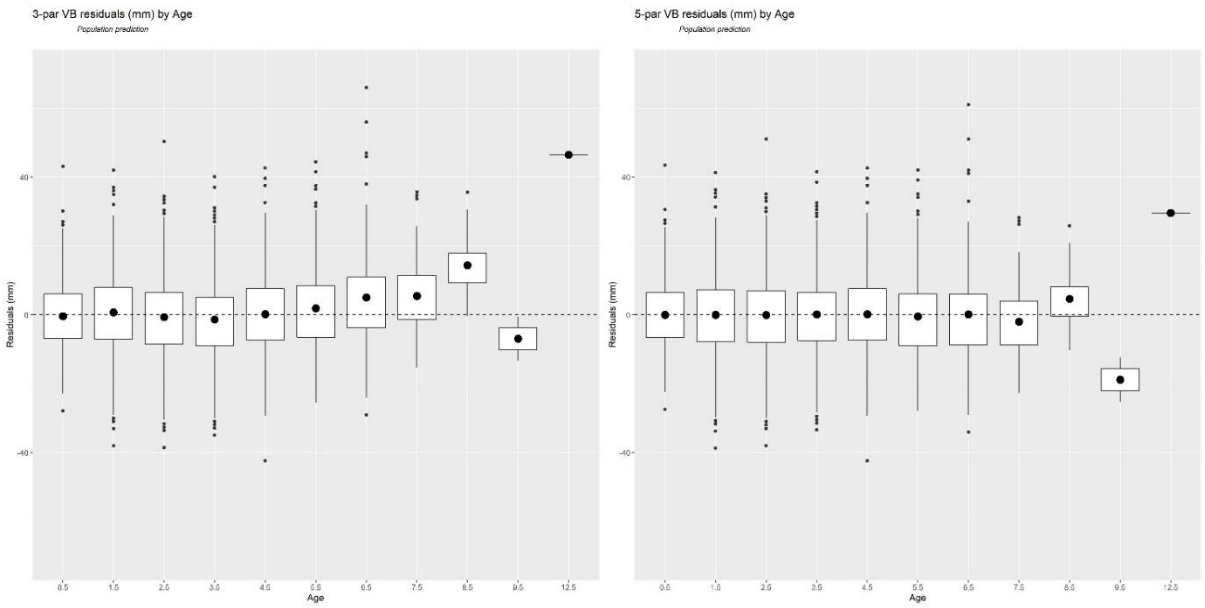


Figure A4: Box plots of the residuals of the von Bertalanffy growth models based on three ('classic' left panel) and five parameters ('biphasic', right panel), defined as the observed length-at-age minus the predicted posterior mean of the model.

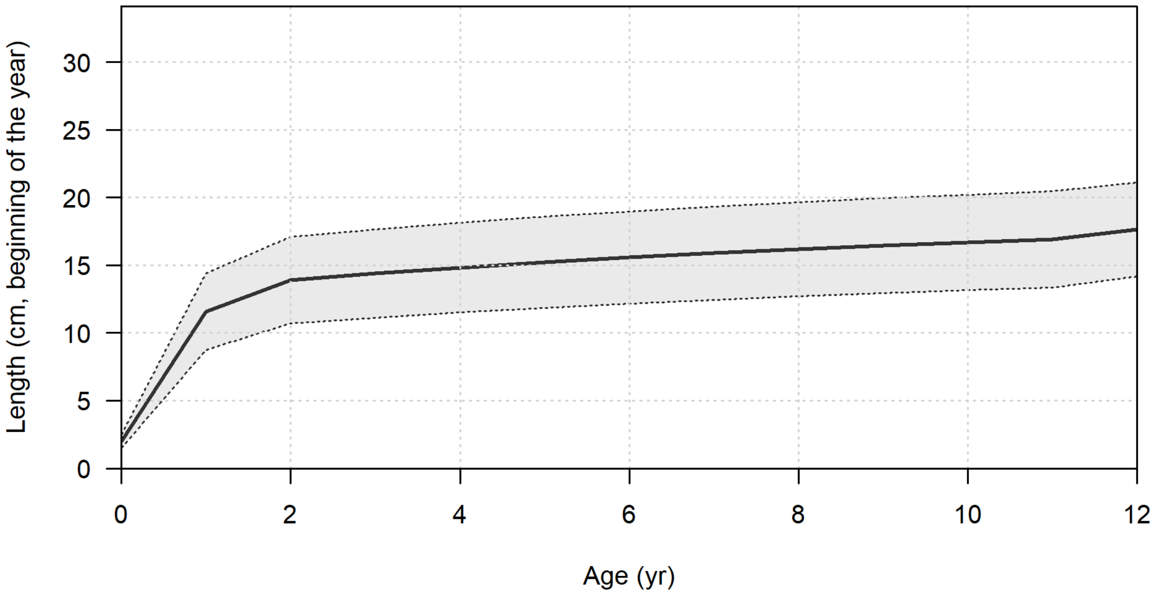


Figure A5: Length at age in the beginning of the year (or season) in the ending year of the SS3 model. Shaded area indicates 95% distribution of length at age around estimated growth curve.

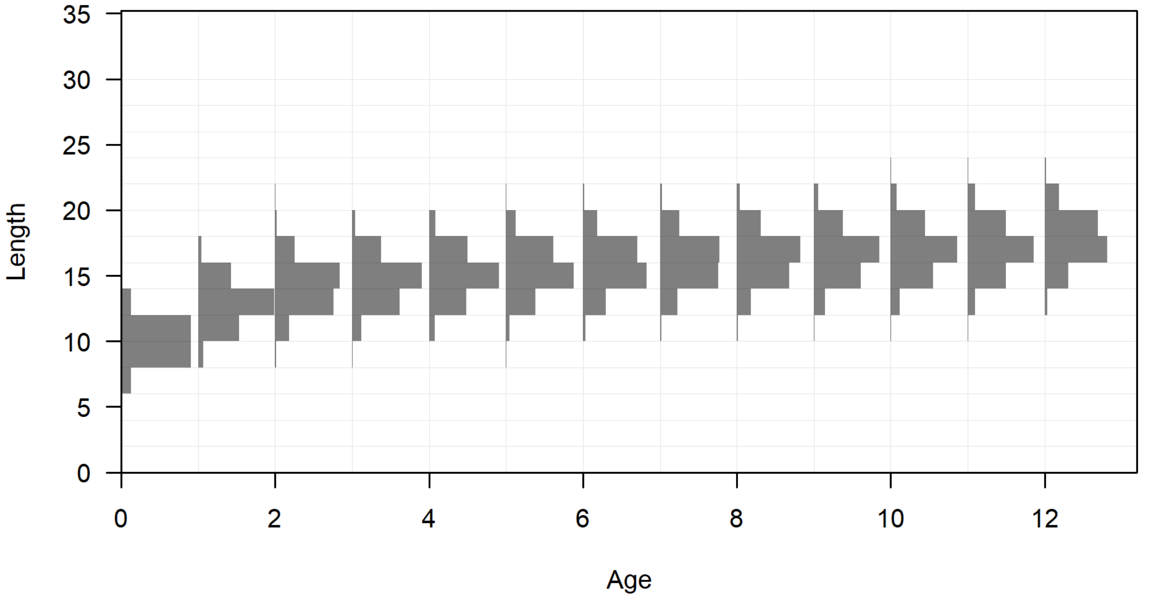


Figure A6: Distribution of length at age at half of the year in SS3.

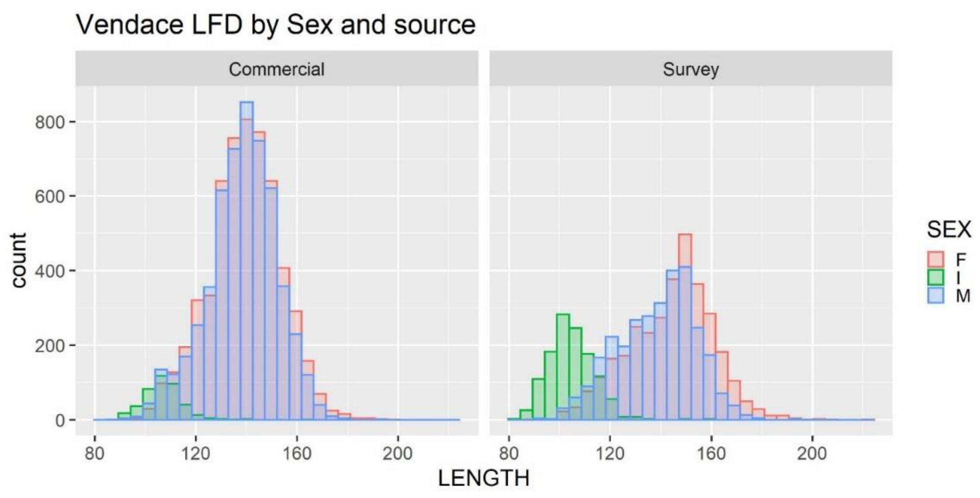


Figure A7: Commercial (left) and survey (right) LFDs, by sex. (F)emale, (I)mmature and (M)ale distributions are denoted by pink, green and blue colours.

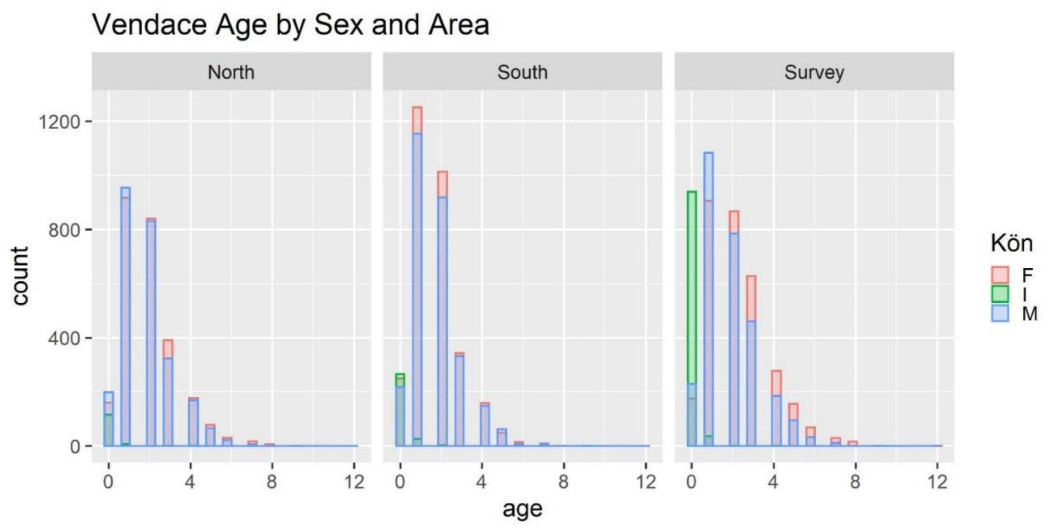
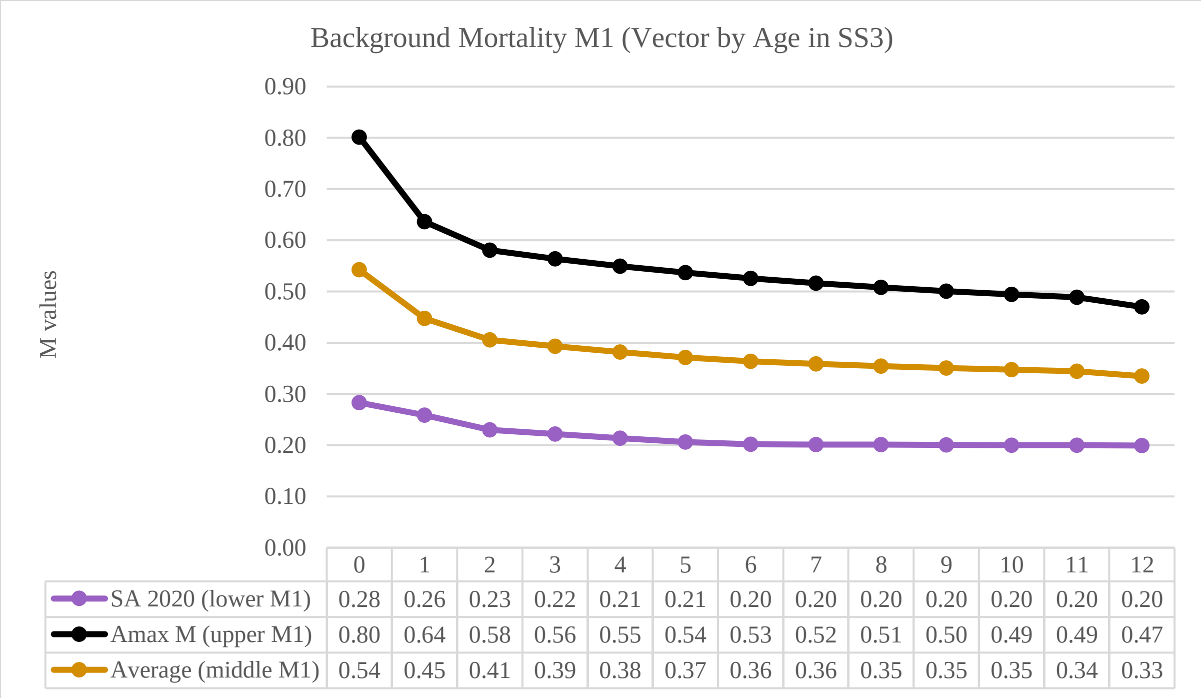


Figure A8: Survey age distributions, by sex and area. (F)emale, (I)mmature and (M)ale distributions are denoted by pink, green and blue colours.



	0	1	2	3	4	5	6	7	8	9	10	11	12
SA 2020 (lower M1)	0.28	0.26	0.23	0.22	0.21	0.21	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Amax M (upper M1)	0.80	0.64	0.58	0.56	0.55	0.54	0.53	0.52	0.51	0.50	0.49	0.49	0.47
Average (middle M1)	0.54	0.45	0.41	0.39	0.38	0.37	0.36	0.36	0.35	0.35	0.35	0.34	0.33

Figure A9: The three natural mortality scenarios to be explored in the assessment. Last year's assessment's M (purple line, 'SA 2020') will be used as the lower limit, the composite M from this analyses (black line, 'Amax M') as the upper limit, and lastly, the average (orange line, 'Average'). Values are taken as the value at maximum age and scaled by the body size-at-age of the fish with Lorenzen option within SS3.

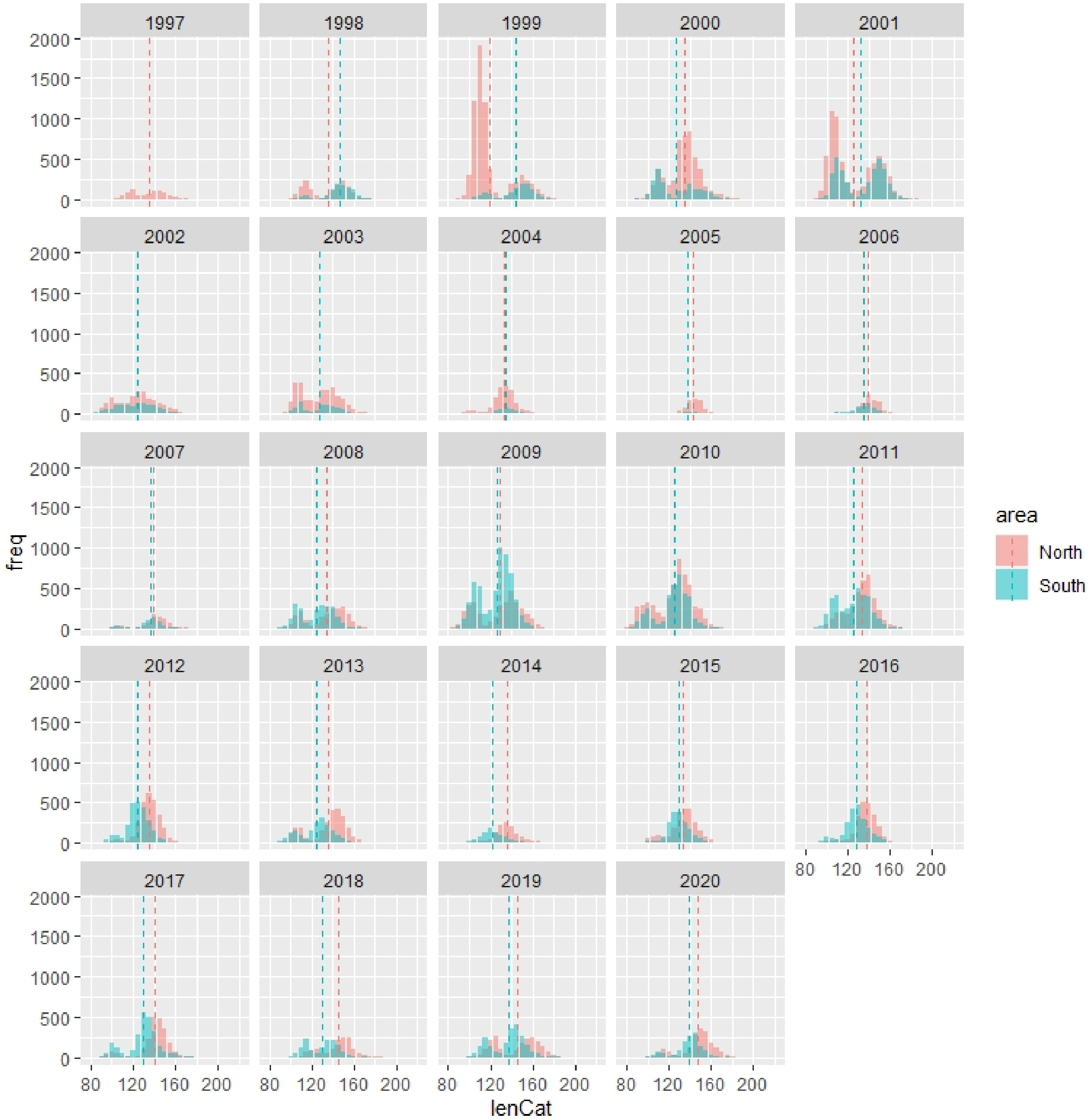


Figure A10: LFDs across years 1997-2020 from the length-classified data, stratified in to northern and southern areas. Dashed vertical lines show mean lengths weighted by number of individuals in each length class.

Figure A11: LFDs across years 1997-2020 from the length-classified data, stratified in to fish caught in September (9) or October (10). Dashed vertical lines show mean lengths weighted by number of individuals in each length class.

Supplementary tables

Table A1: summary statistics for the commercial LFD data, across years, area and fishing month. Means are weighted by the number of individuals per 5 mm size-class. N denotes the number of individuals in all size-classes together.

year	area	month	mean length	N	year	area	month	mean length	N
1997	9	B	138	195	2010	9	E	128	458
1997	10	B	134	657	2010	9	F	127	839
1998	9	B	141	271	2010	10	A	130	806
1998	9	CD	145	88	2010	10	B	130	1645
1998	9	F	133	410	2010	10	CD	122	2055
1998	10	B	139	296	2010	10	E	129	905
1998	10	CD	146	876	2010	10	F	109	1322
1998	10	E	146	57	2011	9	A	142	298
1998	10	F	131	534	2011	9	B	134	336
1999	9	A	159	102	2011	9	CD	131	373
1999	9	B	111	2518	2011	9	E	131	440
1999	9	CD	144	148	2011	9	F	129	433
1999	9	F	121	901	2011	10	A	134	749
1999	10	B	124	1210	2011	10	B	133	822
1999	10	CD	144	955	2011	10	CD	129	1330
1999	10	F	124	1821	2011	10	E	117	1329
2000	9	A	138	253	2011	10	F	131	822
2000	9	B	131	523	2012	9	A	142	357
2000	9	CD	125	439	2012	9	B	135	668
2000	9	E	119	773	2012	9	CD	127	406
2000	9	F	133	475	2012	9	E	126	385
2000	10	A	144	401	2012	10	A	136	562
2000	10	B	136	1574	2012	10	B	136	551
2000	10	CD	137	615	2012	10	CD	125	793
2000	10	F	131	1730	2012	10	E	123	869
2001	9	A	140	408	2012	10	F	131	583
2001	9	B	117	1043	2013	9	A	142	127
2001	9	CD	142	601	2013	9	B	141	506
2001	9	E	143	489	2013	9	CD	131	538
2001	9	F	117	559	2013	10	A	140	169
2001	10	A	135	1237	2013	10	B	137	908
2001	10	B	124	1508	2013	10	CD	124	345
2001	10	CD	128	1845	2013	10	E	121	862
2001	10	E	129	445	2013	10	F	127	825
2001	10	F	123	1304	2014	9	A	139	241
2002	9	B	127	291	2014	9	B	131	354
2002	9	CD	118	480	2014	9	CD	124	358
2002	9	E	124	147	2014	9	E	121	407
2002	10	A	131	476	2014	10	A	140	347
2002	10	B	124	725	2014	10	B	134	279
2002	10	CD	123	424	2014	10	E	117	82

year	area	month	mean length	N	year	area	month	mean length	N
2002	10	E	137	207	2015	9	A	140	178
2002	10	F	120	835	2015	9	B	135	327
2003	9	A	124	470	2015	9	CD	130	357
2003	9	B	124	420	2015	9	E	128	411
2003	9	CD	117	275	2015	10	A	139	436
2003	10	A	124	381	2015	10	B	137	593
2003	10	B	129	1676	2015	10	CD	129	716
2003	10	CD	133	578	2015	10	E	129	313
2004	9	A	143	179	2015	10	F	126	791
2004	9	B	130	176	2016	9	A	141	265
2004	9	CD	128	76	2016	9	B	139	346
2004	9	F	132	221	2016	9	CD	137	357
2004	10	A	136	392	2016	9	E	131	426
2004	10	B	139	193	2016	10	A	140	472
2004	10	CD	136	245	2016	10	B	134	580
2004	10	F	126	499	2016	10	CD	131	619
2005	9	A	148	100	2016	10	E	121	734
2005	9	B	143	86	2016	10	F	136	584
2005	9	CD	137	100	2017	9	A	144	204
2005	10	A	147	200	2017	9	B	144	241
2005	10	B	143	183	2017	9	CD	138	301
2005	10	F	139	195	2017	9	E	131	363
2006	9	A	142	140	2017	9	F	133	274
2006	9	B	136	179	2017	10	A	146	414
2006	10	A	141	292	2017	10	B	143	574
2006	10	B	140	291	2017	10	CD	131	1008
2006	10	CD	135	570	2017	10	E	124	806
2007	9	B	145	196	2017	10	F	134	388
2007	9	CD	132	218	2018	9	A	151	94
2007	10	A	142	147	2018	9	B	150	252
2007	10	B	139	251	2018	9	CD	134	274
2007	10	CD	140	260	2018	9	E	129	346
2007	10	F	128	125	2018	10	A	136	31
2008	9	A	141	143	2018	10	B	149	394
2008	9	B	139	154	2018	10	CD	127	450
2008	9	CD	126	486	2018	10	E	131	305
2008	9	E	118	159	2018	10	F	139	634
2008	9	F	127	217	2019	9	A	151	195
2008	10	A	132	324	2019	9	B	151	321
2008	10	B	138	772	2019	10	A	146	534
2008	10	CD	123	817	2019	10	B	148	240
2008	10	E	126	668	2019	10	CD	138	1086
2008	10	F	129	349	2019	10	E	136	1101
2009	9	A	140	344	2019	10	F	139	668
2009	9	CD	128	1601	2020	9	A	153	220
2009	9	E	134	214	2020	9	B	149	284

year	area	month	mean length	N	year	area	month	mean length	N
2009	9	F	136	321	2020	9	CD	142	170
2009	10	A	134	474	2020	9	E	135	238
2009	10	B	132	1040	2020	9	F	144	142
2009	10	CD	122	2216	2020	10	A	149	433
2009	10	E	128	1571	2020	10	B	147	463
2009	10	F	117	1114	2020	10	CD	138	587
2010	9	A	139	244	2020	10	E	139	340
2010	9	B	133	372	2020	10	F	141	272

Table A2: Summary statistics for the data collected for biological analyses (commercial), across years (A) and years, month and area (B). q1-q3, SD and CI95 denotes the 1st, 2nd (median) and 3rd quartiles, standard deviation and +-95% confidence interval, respectively. N denotes the total sample size per stratification.

		Age (year)							Length (mm)						
A	**year**	**mean**	**q1**	**q2**	**q3**	**SD**	**CI95**	**N**	**mean**	**q1**	**q2**	**q3**	**SD**	**CI95**	**N**
	2001	1.24	0	1	2	1.19	0.073	1025	134.18	113	140	150	20.08	1.23	1026
	2002	1.01	0	1	1	1.01	0.083	559	126.17	112	127	140	19.07	1.15	1065
	2003	0.88	0	1	1	0.86	0.069	595	126.13	108	128	140	17.58	1.21	810
	2004	1.34	1	1	2	0.81	0.081	385	131.47	126	132	138.75	13.73	1.37	386
	2005	1.90	2	2	2	0.8	0.074	449	140.47	134	143	148	13.12	1.21	450
	2006	2.08	1	2	3	1.26	0.111	498	135.68	130	137	143	11.9	0.73	1024
	2007	2.17	1	2	3	1.46	0.128	502	137.92	133	141	147	13.6	0.61	1900
	2008	1.68	1	1	2	1.44	0.127	496	132.33	122	136	143	16.42	1.44	500
	2009	1.74	1	1	2	1.39	0.122	498	135.82	129	137	144	14.33	0.64	1900
	2010	1.26	0	1	2	1.22	0.107	502	127.62	111	129	142	19.24	1.68	502
	2011	1.31	1	1	2	1.12	0.098	504	131.52	118	132	144	17.14	1.50	505
	2012	1.52	1	1	2	1.02	0.09	499	131.47	125	132	139	11.34	0.70	1000
	2013	1.98	1	2	3	1.19	0.099	556	134.59	127	138	145	16.31	1.08	870
	2014	1.46	1	1	2	0.98	0.075	650	131.36	123	131	139	13.24	1.01	654
	2015	1.89	1	2	2	0.97	0.059	1038	133.92	126	134	142	12.77	0.78	1040
	2016	2.11	1	2	3	1.17	0.103	501	134.86	129	135	142	11.29	0.71	980
	2017	2.24	1	2	3	1.34	0.111	552	137.40	132	139	146	14.05	0.84	1067
	2018	2.13	1	2	3	1.67	0.124	693	140.36	132	142	151	16.1	0.97	1050
	2019	1.66	1	1	2	1.41	0.088	989	143.22	135	145	155	15.8	0.98	1001
	2020	1.50	1	1	2	1.18	0.073	1004	140.99	135	143	149	13.88	0.86	1010
							Total	**12495**						**Total**	**18740**

				Age (year)							Length (mm)						
B	**year**	**month**	**area**	**mean**	**q1**	**q2**	**q3**	**SD**	**CI95**	**N**	**mean**	**q1**	**q2**	**q3**	**SD**	**CI95**	**N**
	2001	10	A	0.70	0.00	0.00	1.00	0.89	0.24	53.00	133.00	116.00	130.00	148.00	17.71	4.77	53
	2001	10	B	0.99	0.00	1.00	2.00	0.91	0.11	258.00	134.10	111.25	140.00	153.00	21.56	2.63	258
	2001	10	CD	1.22	0.00	1.00	2.00	1.19	0.13	309.00	130.16	109.00	138.00	147.00	19.20	2.14	309
	2001	10	E	1.07	0.00	1.00	2.00	1.09	0.17	152.00	136.27	117.00	142.00	153.00	18.66	2.97	152
	2001	9	A	1.43	1.00	2.00	2.00	1.12	0.31	49.00	142.74	130.25	149.00	155.00	18.11	5.02	50
	2001	9	B	1.02	0.00	1.00	2.00	0.97	0.26	53.00	127.06	104.00	135.00	146.00	22.07	5.94	53
	2001	9	CD	1.95	1.00	2.00	2.00	1.54	0.30	101.00	134.50	131.00	140.00	146.00	18.95	3.70	101
	2001	9	E	2.28	2.00	2.00	3.00	1.29	0.36	50.00	152.62	147.00	152.50	158.75	10.15	2.81	50
	2002	10	A	1.29	1.00	1.00	2.00	1.07	0.19	126.00	135.69	114.00	141.00	151.00	20.19	2.78	202
	2002	10	B	1.14	1.00	1.00	1.00	1.03	0.19	115.00	123.90	114.00	125.00	137.00	18.71	2.30	254
	2002	10	CD	0.79	0.00	1.00	1.00	0.97	0.14	182.00	120.94	106.00	121.00	134.00	17.77	2.19	254
	2002	10	E	1.09	0.00	1.00	2.00	1.11	0.27	67.00	129.81	115.00	131.00	142.50	15.90	2.19	203
	2002	10	F	0.81	0.00	1.00	1.00	0.65	0.15	69.00	121.17	106.75	124.00	133.25	18.61	2.96	152
	2003	10	A	0.65	0.00	0.00	1.00	0.95	0.18	107.00	121.29	107.00	113.00	139.00	19.18	3.04	153
	2003	10	B	1.03	1.00	1.00	1.00	0.75	0.10	217.00	129.70	119.50	131.00	141.00	16.04	1.79	307
	2003	10	CD	1.11	1.00	1.00	2.00	0.80	0.16	91.00	130.27	121.00	132.00	141.00	13.79	2.18	153
	2003	9	A	0.77	0.00	0.00	1.00	0.96	0.22	73.00	122.00	104.25	110.50	141.50	21.50	4.65	82
	2003	9	B	0.54	0.00	0.00	1.00	0.85	0.21	61.00	116.94	106.00	108.00	128.25	16.51	4.04	64
	2003	9	CD	0.87	0.00	1.00	1.75	0.81	0.23	46.00	124.88	108.00	128.00	138.50	17.27	4.74	51
	2004	10	A	1.27	1.00	1.00	1.00	0.91	0.27	45.00	130.02	127.00	129.00	135.00	13.99	4.09	45
	2004	10	B	1.53	1.00	1.00	2.00	0.99	0.24	64.00	134.52	129.00	134.00	138.25	10.95	2.68	64
	2004	10	CD	1.53	1.00	1.00	2.00	0.80	0.19	68.00	132.49	129.00	133.00	137.00	10.23	2.43	68
	2004	10	F	1.17	1.00	1.00	2.00	0.67	0.16	65.00	125.38	119.00	128.00	133.00	13.80	3.35	65
	2004	9	A	1.20	1.00	1.00	1.00	0.76	0.25	35.00	138.72	133.75	139.00	147.75	17.60	5.75	36
	2004	9	B	1.19	1.00	1.00	2.00	0.58	0.19	36.00	130.78	128.75	132.00	137.00	10.46	3.42	36
	2004	9	CD	1.39	1.00	1.00	2.00	0.73	0.24	36.00	131.42	126.00	130.50	140.00	13.89	4.54	36
	2004	9	F	1.25	1.00	1.00	2.00	0.84	0.27	36.00	130.47	119.75	132.00	142.25	17.49	5.71	36
	2005	10	A	1.86	2.00	2.00	2.00	0.82	0.16	100.00	144.57	141.00	147.00	152.00	13.92	2.73	100
	2005	10	B	1.92	2.00	2.00	2.00	0.72	0.14	100.00	140.54	136.00	142.50	146.00	10.72	2.10	100

2005	10	F	1.82	1.00	2.00	2.00	0.82	0.16	100.00	137.11	131.00	138.00	146.00	13.18	2.58	100
2005	9	A	2.06	2.00	2.00	2.75	0.98	0.27	50.00	142.76	139.25	145.00	152.00	14.69	4.07	50
2005	9	B	2.08	2.00	2.00	2.00	0.53	0.15	49.00	142.72	138.00	143.00	148.00	8.04	2.23	50
2005	9	CD	1.72	1.00	2.00	2.00	0.86	0.24	50.00	134.28	127.00	135.00	143.00	14.68	4.07	50
2006	10	A	2.54	2.00	3.00	3.00	1.19	0.27	72.00	141.67	138.00	145.00	151.00	12.93	2.05	153
2006	10	B	2.16	1.00	2.00	3.00	1.05	0.23	81.00	140.25	134.25	142.00	146.00	10.27	1.62	154
2006	10	CD	2.02	1.00	2.00	3.00	1.27	0.23	115.00	132.96	128.00	134.00	140.00	10.75	1.32	255
2006	10	E	1.65	1.00	1.00	2.00	1.14	0.24	89.00	132.99	126.25	133.00	139.75	11.97	1.89	154
2006	10	F	2.01	1.00	2.00	3.00	1.56	0.35	75.00	133.10	129.75	134.50	140.00	10.82	1.72	152
2006	9	B	2.83	2.75	3.00	3.00	1.05	0.42	24.00	140.06	137.75	141.00	145.00	8.58	2.33	52
2006	9	CD	2.15	1.00	2.00	3.00	1.05	0.40	26.00	134.33	127.75	134.00	140.25	9.04	2.46	52
2006	9	F	1.63	1.00	1.00	3.00	1.20	0.59	16.00	130.37	123.00	133.00	141.25	14.82	4.03	52
2007	10	A	2.40	1.00	2.00	4.00	1.58	0.41	57.00	143.19	141.00	146.00	151.00	13.60	2.18	150
2007	10	B	2.53	1.00	2.00	4.00	1.51	0.30	96.00	144.94	141.00	146.00	151.00	10.37	0.96	450
2007	10	CD	2.07	1.00	2.00	3.00	1.34	0.24	118.00	133.39	131.00	136.00	141.00	12.88	1.19	450
2007	10	E	1.42	0.00	1.00	2.00	1.26	0.26	91.00	130.95	122.00	134.00	141.00	13.80	1.28	450
2007	10	F	2.31	2.00	2.00	3.00	1.46	0.40	51.00	142.01	138.00	142.50	148.00	9.98	1.60	150
2007	9	A	3.58	3.00	4.00	4.00	1.43	0.64	19.00	150.62	147.25	151.00	155.00	6.15	1.71	50
2007	9	B	2.56	2.00	2.00	4.00	1.15	0.56	16.00	146.46	141.00	146.50	152.75	9.75	2.70	50
2007	9	CD	1.79	0.50	2.00	2.00	1.40	0.63	19.00	133.62	131.25	137.50	142.00	13.77	3.82	50
2007	9	E	2.17	1.00	2.00	3.00	1.25	0.41	35.00	135.63	131.00	138.00	143.00	10.74	2.10	100
2008	10	A	1.92	0.00	1.00	3.00	1.95	0.63	37.00	137.95	114.00	147.00	152.00	19.91	6.41	37
2008	10	B	2.11	1.00	2.00	3.00	1.46	0.29	99.00	142.64	138.00	144.00	152.00	13.34	2.63	99
2008	10	CD	1.36	0.00	1.00	2.00	1.31	0.25	104.00	126.83	113.75	129.00	136.25	14.13	2.72	104
2008	10	E	1.49	0.00	1.50	2.00	1.26	0.21	136.00	126.99	110.00	131.50	138.00	14.64	2.44	138
2008	10	F	1.47	1.00	1.00	2.00	1.41	0.49	32.00	132.48	118.00	137.00	147.00	17.99	6.14	33
2008	9	A	2.78	2.00	2.00	4.00	1.56	1.02	9.00	150.44	148.00	152.00	157.00	12.30	8.04	9
2008	9	B	1.60	0.25	1.00	2.00	1.84	1.14	10.00	129.70	117.50	133.50	144.50	19.68	12.20	10
2008	9	CD	1.95	1.00	2.00	3.00	1.39	0.44	39.00	132.65	125.50	135.00	141.25	13.84	4.29	40
2008	9	E	1.28	0.00	1.00	2.00	1.36	0.63	18.00	124.94	106.50	127.00	139.50	17.87	8.26	18
2008	9	F	1.75	1.00	1.50	2.25	1.14	0.64	12.00	137.08	136.75	139.50	142.00	13.10	7.41	12

2009	10	A	2.00	1.00	2.00	3.00	1.76	0.51	45.00	144.35	139.00	148.00	154.00	16.29	2.61	150
2009	10	B	1.85	1.00	1.00	2.00	1.52	0.27	121.00	142.24	136.00	142.00	151.00	12.77	1.18	450
2009	10	CD	1.79	1.00	1.00	2.00	1.43	0.29	91.00	130.71	127.00	133.00	139.00	13.35	1.40	350
2009	10	E	1.70	1.00	1.00	2.00	1.15	0.20	122.00	132.56	127.00	134.00	141.00	11.93	1.10	450
2009	10	F	1.42	1.00	1.00	2.00	0.86	0.27	38.00	133.70	127.00	133.00	142.75	13.90	2.22	150
2009	9	A	2.00	1.00	2.00	3.00	1.73	0.88	15.00	142.92	141.00	147.50	153.00	18.10	5.02	50
2009	9	B	1.14	1.00	1.00	1.00	0.53	0.28	14.00	137.52	132.00	138.00	145.50	13.63	3.78	50
2009	9	CD	1.69	1.00	1.00	2.00	1.75	0.61	32.00	129.40	127.00	131.00	137.00	13.28	2.13	150
2009	9	E	1.33	1.00	1.00	2.00	0.87	0.57	9.00	132.00	127.25	133.50	138.75	11.92	3.30	50
2009	9	F	1.55	1.00	1.00	2.00	0.82	0.48	11.00	138.30	131.25	136.50	146.50	14.10	3.91	50
2010	10	A	0.85	0.00	1.00	1.00	0.78	0.26	34.00	128.82	110.25	137.00	141.00	18.11	6.09	34
2010	10	B	1.21	0.00	1.00	2.00	1.09	0.22	92.00	131.42	112.75	131.00	147.00	20.50	4.19	92
2010	10	CD	1.16	0.00	1.00	1.00	1.36	0.28	88.00	121.09	103.00	124.00	134.00	18.20	3.80	88
2010	10	E	1.55	0.00	1.00	2.00	1.51	0.36	69.00	130.36	108.00	133.00	147.00	21.34	5.04	69
2010	10	F	0.79	0.00	1.00	1.00	1.24	0.39	39.00	113.97	99.00	115.00	123.00	16.50	5.18	39
2010	9	A	1.69	1.00	1.00	2.00	1.16	0.38	35.00	140.09	135.00	143.00	150.00	13.87	4.59	35
2010	9	B	1.44	1.00	1.00	2.00	0.99	0.33	34.00	133.09	118.25	135.00	146.50	17.93	6.03	34
2010	9	E	1.54	1.00	1.00	2.00	1.15	0.32	50.00	129.62	124.25	134.00	140.00	16.27	4.51	50
2010	9	F	1.15	1.00	1.00	1.00	1.06	0.27	61.00	124.43	118.00	127.00	135.00	16.35	4.10	61
2011	10	A	1.30	0.00	1.00	2.00	1.37	0.33	66.00	134.80	118.00	138.00	148.00	17.17	4.14	66
2011	10	B	1.58	1.00	1.50	2.00	0.97	0.39	24.00	138.00	127.75	141.00	150.25	15.21	6.08	24
2011	10	CD	1.11	0.00	1.00	2.00	1.07	0.24	76.00	125.96	111.75	124.50	139.00	18.16	4.08	76
2011	10	E	1.15	0.00	1.00	2.00	1.16	0.25	86.00	127.05	112.00	124.50	141.00	17.91	3.79	86
2011	10	F	1.11	1.00	1.00	2.00	0.82	0.22	53.00	127.51	116.00	128.00	140.00	15.84	4.27	53
2011	9	A	2.09	1.00	2.00	2.00	1.76	0.53	43.00	144.33	140.00	147.00	154.00	16.24	4.86	43
2011	9	B	1.43	1.00	1.00	2.00	0.70	0.23	35.00	133.91	124.50	133.00	142.00	13.68	4.53	35
2011	9	CD	1.31	1.00	1.00	2.00	0.75	0.23	42.00	131.51	123.00	132.00	141.00	15.33	4.58	43
2011	9	E	1.39	1.00	1.00	2.00	0.87	0.28	36.00	132.28	122.50	135.50	143.00	15.13	4.94	36
2011	9	F	1.16	1.00	1.00	1.00	0.72	0.22	43.00	131.19	123.00	133.00	141.50	14.90	4.45	43
2012	10	A	1.79	1.00	2.00	2.75	1.37	0.35	58.00	135.63	129.00	135.00	144.00	11.60	1.97	133
2012	10	B	1.42	1.00	1.00	2.00	0.59	0.18	43.00	133.67	128.00	134.00	138.00	6.97	1.17	136

2012	10	CD	1.34	1.00	1.00	2.00	1.03	0.25	64.00	126.46	120.00	127.00	134.00	12.19	2.12	127
2012	10	E	0.91	0.00	1.00	1.00	0.90	0.24	56.00	125.47	120.00	127.00	133.00	11.26	1.89	137
2012	10	F	1.47	1.00	1.00	2.00	1.03	0.27	55.00	130.65	125.00	130.00	137.00	10.51	1.78	134
2012	9	A	2.13	1.00	2.00	3.00	1.11	0.35	40.00	141.24	136.00	141.00	146.00	7.00	1.66	68
2012	9	B	1.64	1.00	2.00	2.00	0.70	0.15	85.00	134.50	129.00	135.00	140.00	9.84	1.70	129
2012	9	CD	1.85	1.00	2.00	3.00	1.12	0.32	47.00	130.06	121.75	130.00	139.25	12.42	2.95	68
2012	9	E	1.29	1.00	1.00	1.00	0.81	0.22	51.00	127.81	121.75	128.00	133.25	10.61	2.52	68
2013	10	A	1.80	1.00	2.00	3.00	1.21	0.36	44.00	139.78	138.00	143.00	148.00	14.13	3.36	68
2013	10	B	2.03	2.00	2.00	2.00	1.10	0.20	118.00	139.55	135.00	144.00	150.00	18.08	2.61	184
2013	10	CD	1.93	1.00	2.00	3.00	1.18	0.36	42.00	127.43	123.00	128.00	135.50	13.55	3.35	63
2013	10	E	1.37	0.00	2.00	2.00	0.98	0.24	65.00	124.04	107.75	126.00	135.00	17.34	3.10	120
2013	10	F	1.59	0.00	1.00	3.00	1.50	0.35	69.00	128.50	110.00	133.00	140.00	18.06	3.22	121
2013	9	A	2.48	2.00	3.00	3.00	1.33	0.40	42.00	142.17	140.00	143.00	148.00	11.77	2.86	65
2013	9	B	2.23	2.00	2.00	3.00	0.91	0.20	81.00	140.17	135.00	140.00	145.00	10.21	1.81	123
2013	9	CD	2.35	2.00	2.00	3.00	1.22	0.34	49.00	136.89	131.00	136.00	144.50	11.94	2.95	63
2013	9	E	2.20	2.00	2.00	3.00	0.98	0.28	46.00	132.40	127.50	132.00	138.50	9.56	2.36	63
2014	10	A	1.75	1.00	1.00	3.00	1.16	0.19	142.00	139.43	133.00	138.00	145.00	11.41	1.87	143
2014	10	B	1.34	1.00	1.00	1.00	0.86	0.14	149.00	135.54	128.00	134.00	142.00	11.31	1.82	149
2014	10	E	1.06	1.00	1.00	1.00	0.83	0.18	81.00	119.50	110.25	118.50	128.00	11.50	2.49	82
2014	9	A	1.87	1.00	1.00	3.00	1.17	0.28	69.00	135.99	130.00	137.00	143.75	11.25	2.64	70
2014	9	B	1.21	1.00	1.00	1.00	0.66	0.15	70.00	129.16	125.00	128.50	134.00	10.09	2.36	70
2014	9	CD	1.50	1.00	1.00	2.00	0.94	0.22	70.00	124.74	116.25	123.50	132.75	11.47	2.69	70
2014	9	E	1.36	1.00	1.00	2.00	0.77	0.18	69.00	124.03	117.25	124.00	129.75	11.70	2.74	70
2015	10	A	2.27	2.00	2.00	3.00	1.04	0.16	160.00	143.31	138.00	144.00	150.00	11.08	1.72	160
2015	10	B	1.86	2.00	2.00	2.00	0.72	0.11	160.00	135.99	130.00	136.00	141.00	9.07	1.40	160
2015	10	CD	1.69	1.00	2.00	2.00	0.90	0.14	160.00	129.49	123.00	128.00	135.25	13.14	2.04	160
2015	10	E	1.90	1.50	2.00	2.00	0.81	0.18	79.00	129.70	120.75	130.00	137.25	11.58	2.54	80
2015	10	F	1.52	1.00	2.00	2.00	1.01	0.16	159.00	126.84	122.00	128.00	135.00	13.34	2.07	160
2015	9	A	2.38	2.00	2.00	3.00	1.18	0.26	80.00	145.48	142.00	147.50	151.25	10.58	2.32	80
2015	9	B	1.86	2.00	2.00	2.00	0.72	0.16	80.00	134.69	130.00	136.00	140.00	7.68	1.68	80
2015	9	CD	1.81	1.00	2.00	2.00	0.92	0.20	80.00	131.30	124.00	130.00	139.00	10.75	2.36	80

2015	9	E	1.98	1.00	2.00	2.00	1.03	0.23	80.00	128.58	123.00	127.00	135.25	9.34	2.05	80
2016	10	A	2.55	2.00	3.00	3.00	1.34	0.34	58.00	140.74	134.75	140.00	148.00	10.46	1.73	140
2016	10	B	2.33	1.00	2.00	3.00	1.30	0.30	72.00	136.67	131.00	136.00	141.00	8.63	1.16	211
2016	10	CD	1.89	1.00	2.00	2.75	0.90	0.24	54.00	133.83	128.00	133.00	138.50	9.37	1.56	139
2016	10	E	1.37	1.00	1.00	2.00	1.12	0.25	75.00	123.18	119.00	123.00	131.00	10.51	1.74	140
2016	10	F	1.81	1.00	2.00	3.00	0.93	0.32	32.00	136.31	132.00	136.00	140.50	9.44	2.20	71
2016	9	B	2.28	1.00	2.00	3.00	1.10	0.22	96.00	139.19	135.00	140.00	145.00	8.87	1.47	139
2016	9	CD	2.33	2.00	2.00	3.00	0.85	0.23	54.00	137.43	130.00	135.00	142.75	11.94	2.80	70
2016	9	E	2.25	1.00	2.00	3.00	1.16	0.29	60.00	130.47	123.00	128.00	134.00	12.13	2.84	70
2017	10	A	2.97	2.00	3.00	4.00	1.21	0.30	62.00	145.61	142.00	146.00	152.00	11.06	1.88	133
2017	10	B	2.70	2.00	3.00	3.00	1.01	0.26	56.00	144.17	140.00	144.00	148.00	6.92	1.16	137
2017	10	CD	2.30	1.00	2.00	4.00	1.41	0.24	129.00	135.60	130.00	136.00	143.00	13.53	1.61	270
2017	10	E	1.61	1.00	1.00	2.00	1.08	0.28	59.00	130.01	125.00	130.00	136.00	13.22	2.26	131
2017	10	F	1.47	0.00	1.00	2.75	1.41	0.50	30.00	128.99	105.00	137.00	142.00	19.05	4.56	67
2017	9	A	2.23	2.00	2.00	3.00	1.27	0.38	44.00	140.84	140.00	144.00	148.50	15.60	3.73	67
2017	9	B	2.46	1.50	3.00	3.00	1.27	0.40	39.00	141.84	137.00	142.00	147.00	10.35	2.48	67
2017	9	CD	2.34	2.00	2.00	3.00	1.24	0.34	50.00	136.69	133.00	138.00	143.25	13.36	3.18	68
2017	9	E	1.59	1.00	1.00	2.00	1.41	0.41	46.00	131.93	128.75	133.00	140.00	16.89	4.01	68
2017	9	F	2.27	1.00	2.00	3.00	1.24	0.40	37.00	135.53	131.00	136.00	140.00	9.57	2.44	59
2018	10	A	2.61	1.00	3.00	4.00	2.00	0.41	90.00	147.68	128.00	153.00	161.00	18.07	3.52	101
2018	10	B	2.50	1.00	3.00	4.00	1.81	0.34	107.00	144.48	137.50	145.00	154.00	15.77	2.31	179
2018	10	CD	1.60	0.50	1.00	2.00	1.48	0.28	107.00	135.44	130.00	139.00	144.00	14.27	1.92	212
2018	10	E	1.03	0.00	1.00	2.00	1.15	0.38	35.00	128.24	114.25	133.00	139.75	13.34	3.13	70
2018	10	F	1.87	0.00	2.00	3.00	1.55	0.29	113.00	139.33	125.00	143.00	150.00	17.93	2.44	207
2018	9	A	3.12	2.00	3.00	4.00	1.44	0.35	65.00	150.49	148.00	152.00	155.75	7.66	1.79	70
2018	9	B	2.69	2.00	2.00	3.00	1.16	0.30	58.00	150.43	146.00	149.00	155.00	8.88	2.08	70
2018	9	CD	1.97	1.00	2.00	3.00	1.72	0.44	59.00	135.71	131.00	136.00	142.00	14.23	3.36	69
2018	9	E	1.34	1.00	1.00	2.00	1.03	0.26	59.00	133.86	130.00	134.00	140.00	10.09	2.33	72
2019	10	A	1.92	0.00	2.00	3.00	1.76	0.30	133.00	148.51	129.00	155.00	162.25	18.27	3.07	136
2019	10	B	1.80	1.00	1.00	2.00	1.62	0.27	135.00	147.21	143.00	150.00	158.00	16.30	2.74	136
2019	10	CD	1.54	1.00	1.00	2.00	1.18	0.17	188.00	140.18	135.00	142.00	148.00	13.39	1.90	191

2019	10	E	1.39	1.00	1.00	2.00	1.14	0.16	200.00	134.92	131.00	138.00	142.00	12.35	1.71	201
2019	10	F	1.57	1.00	1.00	2.00	1.15	0.20	133.00	143.16	138.50	145.00	151.00	12.50	2.11	135
2019	9	A	2.10	1.00	2.00	3.00	1.62	0.39	67.00	154.84	153.00	157.00	163.00	12.64	3.03	67
2019	9	B	1.68	0.75	1.50	2.00	1.53	0.26	132.00	144.85	131.75	150.50	157.75	17.68	2.99	134
2019	9	E	1.00	1.00	1.00	1.00	NA	NA	1.00	144.00	144.00	144.00	144.00	NA	NA	1
2020	10	A	1.54	1.00	1.00	2.00	1.48	0.25	135.00	145.93	141.50	148.00	155.00	15.42	2.60	135
2020	10	B	1.48	1.00	1.00	2.00	1.18	0.20	132.00	145.86	142.00	146.00	151.00	10.91	1.86	132
2020	10	CD	1.48	1.00	1.00	2.00	1.10	0.19	135.00	138.26	132.00	140.00	146.00	13.22	2.22	136
2020	10	E	1.64	1.00	2.00	2.00	1.14	0.19	135.00	135.03	130.00	137.00	143.00	11.67	1.95	137
2020	10	F	1.16	1.00	1.00	1.00	0.96	0.16	134.00	137.64	132.00	141.00	146.50	16.03	2.70	135
2020	9	A	1.64	1.00	1.00	2.00	1.53	0.37	67.00	146.51	142.00	148.00	154.00	13.13	3.14	67
2020	9	B	1.39	1.00	1.00	1.50	1.33	0.32	67.00	143.33	141.50	148.00	152.00	15.42	3.69	67
2020	9	CD	1.59	1.00	1.00	2.00	0.99	0.24	66.00	140.44	136.00	141.50	145.75	11.79	2.84	66
2020	9	E	1.62	1.00	1.00	2.00	0.91	0.22	65.00	136.04	130.00	134.00	142.00	12.41	2.97	67
2020	9	F	1.66	1.00	1.50	2.00	0.84	0.20	68.00	143.56	137.75	143.50	151.00	9.42	2.24	68
								Total	**12495**						**Total**	**18740**

Table A3: Summary statistics for the data collected for biological analyses (survey), across years (A) and years, month and area (B). q1-q3, SD and CI95 denotes the 1st, 2nd (median) and 3rd quartiles, standard deviation and +-95% confidence interval, respectively. N denotes the total sample size per grouping.

				Age (year)							Length (mm)					
A	**year**	**mean**	**q1**	**q2**	**q3**	**SD**	**CI95**	**N**	**mean**	**q1**	**q2**	**q3**	**SD**	**CI95**	**N**
	2009	1.96	1	1	3	1.842	0.188	369	133.32	120	135	150	22.35	2.28	369
	2010	1.64	0	1	2	1.689	0.128	664	127.36	105	130	145	23.72	1.804	664
	2011	1.84	1	1	3	1.645	0.118	746	129.34	115	130	145	19.91	1.428	747
	2012	1.74	1	1	2	1.711	0.121	765	131.44	117	132	147	22.04	1.562	765
	2013	1.17	0	1	2	1.206	0.081	849	126.90	109	128	143	20	1.342	853
	2014	1.43	1	1	2	1.173	0.085	738	130.24	116	131	145	18.11	1.306	739
	2016	1.53	0	1	3	1.298	0.309	68	127.00	110.75	128	142	18.26	4.34	68
	2017	2.18	1	2	3	1.395	0.104	697	139.81	130	145	150	19.29	1.432	697
	2018	2.07	1	2	3	1.752	0.115	897	139.83	125	145	150	18.48	1.209	898
	2019	1.78	1	2	2	1.451	0.096	880	145.58	135	150	160	19.48	1.287	880
	2020	1.74	1	2	2	1.257	0.086	816	145.47	140	150	155	15.21	1.043	816
							Total	**7489**						**Total**	**7496**

						Age (year)							Length (mm)				
B	**year**	**month**	**area**	**mean**	**q1**	**q2**	**q3**	**SD**	**CI95**	**N**	**mean**	**q1**	**q2**	**q3**	**SD**	**CI95**	**N**
	2009	9	B	2.17	1.00	2.00	3.00	1.60	0.43	53	145.38	135.00	145.00	160.00	20.38	5.49	53
	2009	9	CD	2.05	1.00	2.00	3.00	1.78	0.32	118	131.95	120.00	135.00	150.00	20.86	3.76	118
	2009	9	E	2.18	1.00	1.00	3.50	2.02	0.36	123	135.45	120.00	135.00	150.00	21.20	3.75	123
	2009	9	F	1.31	0.00	1.00	2.00	1.65	0.37	75	123.47	102.50	125.00	145.00	23.45	5.31	75
	2010	9	B	1.46	0.00	1.00	2.00	1.50	0.24	153	128.59	105.00	130.00	150.00	24.21	3.84	153
	2010	9	CD	1.99	1.00	1.00	3.00	1.78	0.27	162	130.06	115.00	135.00	150.00	23.60	3.63	162
	2010	9	E	1.47	0.00	1.00	2.00	1.66	0.20	257	124.82	105.00	125.00	140.00	23.85	2.92	257
	2010	9	F	1.84	1.00	1.00	3.00	1.82	0.37	92	127.61	120.00	130.00	141.25	22.39	4.58	92
	2011	9	B	1.93	1.00	2.00	2.00	1.24	0.25	97	136.24	125.00	135.00	150.00	16.41	3.27	97
	2011	9	CD	2.07	1.00	2.00	3.00	1.53	0.21	203	132.56	120.00	135.00	145.00	18.36	2.53	203
	2011	9	E	1.83	0.00	1.00	3.00	1.90	0.21	319	127.19	110.00	130.00	145.00	20.98	2.30	320

2011	9	F	1.43	1.00	1.00	2.00	1.32	0.23	127		124.33	110.00	125.00	140.00	19.92	3.47	127
2012	9	B	1.11	0.00	1.00	1.00	1.52	0.28	110		127.64	107.25	127.00	141.00	21.85	4.08	110
2012	9	CD	2.02	1.00	2.00	3.00	1.55	0.19	253		135.64	124.00	137.00	150.00	20.39	2.51	253
2012	9	E	1.81	0.75	1.00	3.00	1.93	0.23	280		129.44	110.00	128.00	146.00	23.08	2.70	280
2012	9	F	1.57	1.00	1.00	2.00	1.52	0.27	122		130.77	116.00	129.00	144.25	21.97	3.90	122
2013	11	B	1.82	1.00	2.00	3.00	1.29	0.29	78		142.49	127.50	147.00	155.00	17.92	3.95	79
2013	11	CD	1.25	0.00	1.00	2.00	1.20	0.14	284		128.63	110.00	129.00	146.00	20.66	2.40	284
2013	11	E	0.94	0.00	1.00	2.00	1.06	0.12	328		122.51	106.00	122.00	137.00	18.55	2.00	331
2013	11	F	1.20	0.00	1.00	2.00	1.32	0.20	159		125.19	110.00	127.00	140.00	18.60	2.89	159
2014	10	B	1.96	1.00	2.00	3.00	1.30	0.19	187		140.27	127.50	145.00	152.00	17.49	2.51	187
2014	10	CD	1.30	0.00	1.00	2.00	1.10	0.14	237		126.59	111.25	127.00	141.00	18.16	2.31	238
2014	10	E	1.32	1.00	1.00	2.00	1.03	0.14	201		127.76	116.00	127.00	139.00	15.94	2.20	201
2014	10	F	1.00	0.00	1.00	1.00	1.04	0.19	113		125.73	111.00	127.00	138.00	16.59	3.06	113
2016	10	E	1.53	0.00	1.00	3.00	1.30	0.31	68		127.00	110.75	128.00	142.00	18.26	4.34	68
2017	10	B	2.35	2.00	2.00	3.00	1.10	0.19	129		148.18	145.00	150.00	155.00	12.40	2.14	129
2017	10	CD	2.26	1.00	2.00	3.00	1.45	0.19	215		139.37	130.00	145.00	150.00	19.64	2.63	215
2017	10	E	1.93	0.00	2.00	3.00	1.59	0.25	157		128.60	110.00	130.00	145.00	19.81	3.10	157
2017	10	F	2.17	1.00	2.00	3.00	1.32	0.18	196		143.78	135.00	150.00	155.00	18.07	2.53	196
2018	10	B	2.53	1.00	2.00	4.00	1.73	0.28	152		147.52	140.00	150.00	155.00	16.12	2.55	153
2018	10	CD	1.99	1.00	2.00	3.00	1.68	0.16	402		139.70	126.25	145.00	150.00	18.25	1.78	402
2018	10	E	2.23	1.00	2.00	4.00	1.88	0.25	217		138.34	120.00	140.00	150.00	19.38	2.58	217
2018	10	F	1.48	0.00	1.00	3.00	1.59	0.28	126		133.45	120.00	137.50	150.00	17.34	3.03	126
2019	10	B	2.25	1.00	2.00	3.00	1.58	0.24	164		156.95	155.00	160.00	165.00	17.11	2.62	164
2019	10	CD	1.78	1.00	2.00	2.00	1.34	0.15	319		144.42	135.00	150.00	155.00	18.53	2.03	319
2019	10	E	1.64	1.00	1.00	2.00	1.46	0.22	171		138.13	127.50	140.00	150.00	15.84	2.37	171
2019	10	F	1.53	0.00	1.00	2.00	1.42	0.19	226		144.60	126.25	150.00	160.00	21.36	2.78	226
2020	10	B	1.73	1.00	1.00	1.50	1.95	1.15	11		144.09	140.00	145.00	155.00	18.00	10.64	11
2020	10	CD	1.92	1.00	2.00	2.00	1.34	0.12	447		146.34	140.00	150.00	155.00	15.47	1.43	447
2020	10	E	1.73	1.00	2.00	2.00	1.19	0.19	158		142.12	135.00	145.00	150.00	13.08	2.04	158
2020	10	F	1.35	1.00	1.00	2.00	0.97	0.13	200		146.23	145.00	150.00	155.00	15.74	2.18	200
								Total	**7489**							**Total**	**7496**

Table A4: age-length relationships candidate model evaluation, using a forward selection approach. Age at length data were fitted with a multinomial logistic regression model. McF r^2 denotes McFaddens pseudo r-square. Bold candidate models / AICc values show the best model when adding month or area as an additive effect or as an interaction with length, and the best overall model when having 5 areas or aggregating them into North and South.

COMMERCIAL DATA

Area aggregation	Candidate model	ID	df	AICc	ΔAICc	McF r^2
	age ~ length	m1	18	26777.00	646.81	0.826
	age ~ length + month	m2a	27	**26632.98**	502.79	0.828
	age ~ length * month	m2b	36	26639.48	509.29	0.828
	age ~ length + year	m3a	27	26750.10	619.91	0.827
	age ~ length * year	m3b	36	**26677.25**	547.06	0.827
5 AREAS: A, B, CD, E, F	**age ~ length + area**	m4a	54	**26336.90**	206.71	0.830
	age ~ length * area	m4b	90	26368.55	238.36	0.830
2 AREAS: North (A, B, F); South (CD, E)	**age ~ length + area**	m4c	27	26469.23	339.04	0.829
	age ~ length * area	m4d	36	26481.77	351.58	0.829
5 AREAS: A, B, CD, E, F	**age ~ length * year + month + area**	mC1	81	**26130.19**	0.00	0.831
2 AREAS: North (A, B, F); South (CD, E)	age ~ length * year + month + area	mC2	54	26205.45	75.26	0.831

SURVEY DATA

Area aggregation	Candidate model	ID	df	AICc	ΔAICc	McF r^2
	age ~ length	m1	18	16839.02	1723.61	0.697
	age ~ length + month	m2a	36	15961.44	846.03	0.713
	age ~ length * month	m2b	54	**15770.57**	655.16	0.717
	age ~ length + year	m3a	27	16304.58	1189.17	0.707
	age ~ length * year	m3b	36	**16040.29**	924.88	0.712
5 AREAS: A, B, CD, E, F	age ~ length + area	m4a	45	16613.84	1498.43	0.702
	age ~ length * area	m4b	72	**16574.46**	1459.05	0.703
2 AREAS: North (A, B, F); South (CD, E)	age ~ length + area	m4c	27	16665.24	1549.83	0.700
	age ~ length * area	m4d	36	16639.14	1523.73	0.701
2 AREAS: NE (A, B, F); SW (CD, E)	**age ~ len * year + len*month + length * area**	mS1	90	15128.51	13.10	0.730
5 AREAS: A, B, CD, E, F	**age ~ len * year + len*month + length * area**	mS2	126	**15115.41**	0.00	0.732

Table A5: The Kimura test for validating the difference of the VB curves.

tests	hypothesis	chisq	df	p-value
1 Ho vs H1	H1: Linf1=Linf2=Linf3 =Linf	232.70	3	**<0.001**
2 Ho vs H2	H2: K1=K2=K3 =K4	100.03	3	**<0.001**
3 Ho vs H3	H3: t01=t02=t03=t04	61.61	3	**<0.001**
4 Ho vs H4	H4: Linf1=LinfN,K1=KN,t01=t0N	1585.23	9	**<0.001**

Table A6: Background mortality (M1) from a range of life-history based methods.

	Methods	Reference	Input Categories	Input parms	Availability for baltic stock (Y/N, to be derived...)	Input Value	M1 output Value (CV: 0.1)
Vector by age	Gislason	*Gislason et al. 2010*	VBGP	Linf, k, t0	**Y**, derived from bio data (Survey)	Linf: 154; k:0.77; t0: -1.1	0.83 at age 12
	Chen-Wat	*Chen & Watanabe 1989*	Amax & VBGP	Age, k, t0	**Y**, derived from bio data (Survey)	Linf: 154; k:0.77; t0: -1.1	0.77 at age 12
Single M1 value*	Then_nls	*Then et al. 2015*	Amax	maximum age	Y, derived from bio data (Survey)	12	0.50
	Then_lm	*Then et al. 2015*	Amax	maximum age	Y, derived from bio data (Survey)	12	0.45
	Hamel_Amax	*Hamel. 2015; Hamel in pres.*	Amax	maximum age	Y, derived from bio data (Survey)	12	0.45
	ZM_CA_pel	*Alverson and Carney. 1975*	Amax & VBGP	maximum age, k, t0	**Y**, derived from bio data (Survey)	12; k:0.77; t0: -1.1	0.086
	ZM_CA_dem	*Zhang and Megrey. 2006*	Amax & VBGP	maximum age, k, t0	**Y**, derived from bio data (Survey)	12; k:0.77; t0: -1.1	0.026
	Then_VBGF	*Then et al. 2015*	VBGP	Linf, k	**Y**, derived from bio data (Survey)	Linf: 154; k:0.77; t0: -1.1	1.28
	Hamel_k	*Hamel. 2015; Hamel in pres.*	VBGP	k	**Y**, derived from bio data (Survey)	0.77	1.23
	Jensen_k 1	*Jensen 1997*	VBGP	k	**Y**, derived from bio data (Survey)	0.77	1.05
	Jensen_k 2	*Jensen 1997*	VBGP	k	**Y**, derived from bio data (Survey)	0.77	1.12
	Pauly_lt	*Pauly, 1980*	VBGP & Temp	Linf, k, Temp	**N**	-	-
	Roff	*Roff 1984*	VBGP & Mat	k, age at maturity	**Y**, derived from bio data (Survey)	k:0.7; 1.1	1.8
	Jensen_Amat	*Jensen 1996*	Mat	age at maturity	**Y**, derived from bio data (Survey)	1.10	1.50
	Ri_Ef_Amat	*Rikhter & Efanov 1976*	Mat	age at maturity	**Y**, derived from bio data (Survey)	1.10	1.26
	Pauly_wt	*Pauly, 1980*	Weight	Winf, kw, Temp	N	-	-
	McC&Gil	*McCoy, Gillooly. 2008*	Weight	dry weight, Temp	N	-	-
	PnW	*Peterson and Wroblewski. 1984*	Weight	dry weight	N	-	-
	Lorenzen	*Lorenzen 1996*	Weight	wet weight	**Y**, derived from bio data	80 gr	0.85
	GSI	*Gunderson and Dygert. 1988*	GSI	GSI	https://storefish.org/species/coregonus-albula	around 20% in female	0.36

*Single M1 values can be taken as value at maximum age and scaled by the body size-at-age of the fish with Lorenzen option within SS3.

Table A7: The proportion (weight) of total landings, per area and year, used when calculating the ALKs and LFDs based on the commercial data.

	weight	
year	**north**	**south**
1999	0.621535	0.378465
2000	0.792637	0.207363
2001	0.730999	0.269001
2002	0.713528	0.286472
2003	0.718063	0.281937
2004	0.721023	0.278977
2005	0.735432	0.264568
2006	0.658014	0.341986
2007	0.475354	0.524646
2008	0.532941	0.467059
2009	0.602576	0.397424
2010	0.642134	0.357866
2011	0.623713	0.376287
2012	0.612735	0.387265
2013	0.633204	0.366796
2014	0.617742	0.382258
2015	0.566107	0.433893
2016	0.359992	0.640008
2017	0.283371	0.716629
2018	0.376354	0.623646
2019	0.265398	0.734602
2020	0.497458	0.502542
Mean	0.580923	0.419077

SLU ID:

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2016-11-11

Mottagare: Havs- och Vattenmyndigheten

An evaluation report of the vendace survey in the Bothnian Bay

Summary

This is an evaluation report for the vendace survey that has been conducted in the Norrbotten Archipelago in the Bothnian Bay (Sub Division 31) for the last seven years (2009-2015). The main aim of the survey is to collect fishery independent data for inclusion in the stock assessment of vendace. For the survey results to be usable in the assessment a minimum of three to five years of comparable data are needed. The survey design, method and timing need to be consistent from year to year and cohorts must be followed from on year to the next. Currently the vendace stock assessment only includes commercial catch per unit effort data to calibrate (tune) catch at age information from landings. This may result in biased stock estimates, as only the fished part of the population is captured in the analyses. The objectives of the survey are to provide estimates of abundance and biomass of vendace, and to characterize the age, length, weight and maturity structure of the whole stock. Due to the complex migratory behavior of vendace in both space and time and difficulty of finding an appropriate survey vessel within the budget, deciding on the most appropriate time to conduct the survey has proved to be challenging. As the timing of the survey has not been consistent, the results are yet now used in the stock assessment. Through analyzing and comparing information from the survey trials over the last seven years, with the outputs from several stock assessment models we can, however, conclude that the survey should be performed in mid-October when the best estimates for the spawning stock biomass are obtained. For potential improvement to better forecast the coming years, an additional survey during November would be required to provide the abundance of vendace recruits. However, this would require several more years of sampling to be able to be used in the models.

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Background

SLU Aqua is commissioned by HAV to conduct a yearly hydroacoustic survey in Bothnian Bay (as part of project Övervakning kustfisk, Project number 3 HaV-SLU Aqua). Vendace fisheries is one of the most economically important coastal fisheries in Sweden. The survey aimed to provide information for the stock assessment of vendace fisheries that is conducted as part of project No. 11 (Beståndsanalys nationellt reglerade arter i Överenskommelsen HaV-SLU Aqua). Fishery independent data are crucial for appropriate stock assessment to determine the state of the stock. The main aim of the survey has been to estimate the numbers and biomass of vendace in the northwestern part of the Bothnian Bay, and to characterize the age, length, and weight and maturity structure of the population. In addition the survey aimed to provide fishery independent estimates of abundance of bycatch species (e.g. herring, smelt, whitefish, perch, and ruffe) caught in the fishery.

This report is an evaluation of the survey that has been conducted for 7 years, from 2009 to 2015 and gives recommendation for the continuation and timing of the survey which provides valuable fishery independent information for the stock assessment of the vendace fisheries in the Bothnian Bay. The report also provides information on the outcomes of the estimates of numbers and biomass of vendace in the northwestern part of Bothnian Bay, and also the age, length, and weight and maturity structure of the population.

Material and Methods

Vendace

Vendace (*Coregonus albula* (L.)) is a small pelagic freshwater fish that occurs in the brackish waters of the Bothnian Bay in the northern-most part of the Baltic Sea. Vendace behavior in the Bothnian Bay is very complex. There are remarkable diurnal and seasonal changes in vertical and horizontal distribution of vendace due to feeding, spawning, wintering and life history. Commercial trawl fishery on vendace has a large economic value for the Swedish coastal fishery in the northern Baltic Sea, mainly for its roe but also for consumption of its flesh. Because of the early maturation of vendace, the fishery is dominated by a few young age-classes. Vendace spawn during October to December in rivers and less saline coastal areas and show large annual fluctuations in recruitment which may depend on salinity and temperature conditions and also on fishing pressure (Bergenius et al. 2013).

Commercial fisheries

The vast majority of the vendace total landings (95%) in the Norrbotten Archipelago are caught with trawls. The trawl fishing season for vendace starts on September 20th each year and ends usually five weeks later (end of October). The trawl fishery targets vendace pre-spawning shoals during the day, which are aggregated on the sea bottom at about 10-30 meter depths. Pair-trawling (see appendix for definition section 1.1) with bottom trawl nets is used. The highest catches are generally taken during the first weeks in October.

About a half of the vendace passive gear (the capture of fish that is based on movement of the target species towards the gear) catches are taken by fyke nets. Vendace fyke net fishery targets the vendace pre-spawning shoals in the shallow coastal areas (up to 10 m depth). The fyke net fishing season starts at the beginning of September and ends usually in the middle of October. The highest catches are generally taken during the first weeks in September. Subsequently, vendace yields are decreasing gradually until mid-October, followed by the new increase due to appearance of the spawning shoals. Explanation for the earlier termination of the fishing season, compared to trawl fishery, is the high share of spent vendace in the fyke net catches of the second half of October.

The Survey

For a survey to be useful as a calibration (tuning) index in stock assessment analyses it needs to be conducted for at least three years, preferably five. It needs to be comparable from year to year meaning the gear, time and boat should be kept the same and if not it should be calibrated. Certain aspects can be standardized for others not.

Survey area

The survey has been performed in the northwestern part of Swedish exclusive economic zone (EEZ) in the Bothnian Bay (Fig. 1). The survey transect is approximately 250 nautical mile (1 n.mi. = 1.852 km) long and covers the areas which are the most important fishing grounds for vendace fisheries.

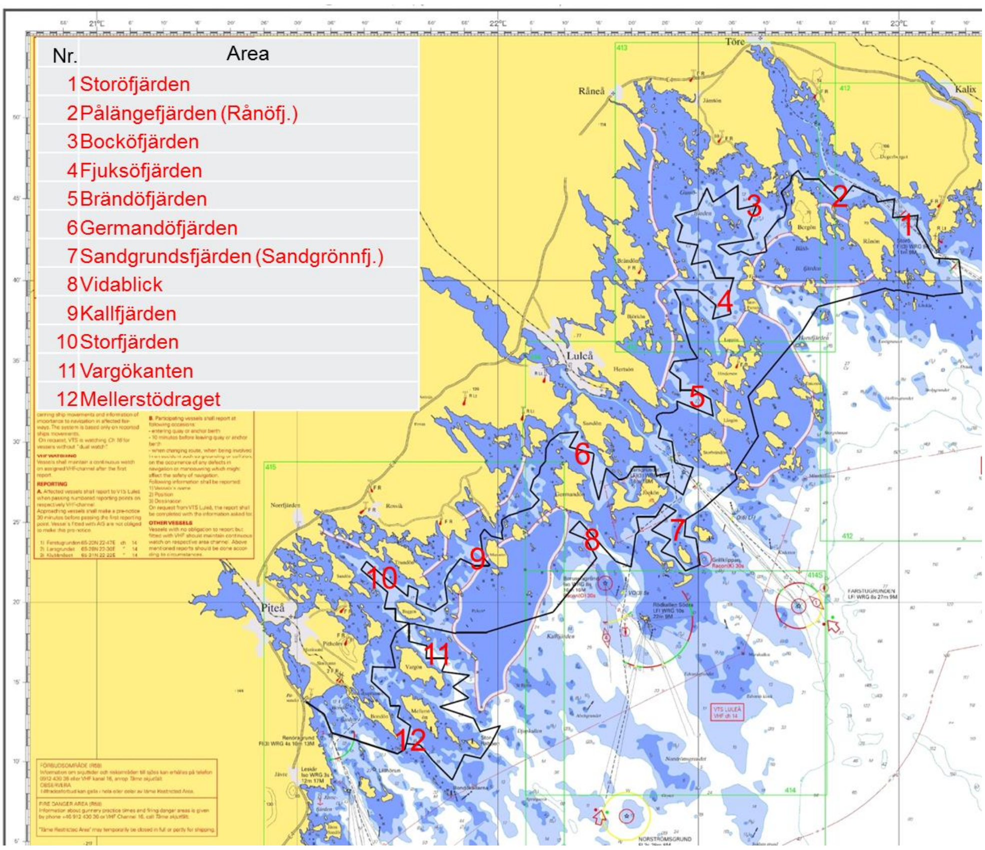

Figure 1. Map of the survey area showing the survey transect and different sampling stations in the Norrbotten Archipelago, the Bothnian Bay. (One minute on the latitude scale bar equals to one nautical mile.)

Survey time

The survey has been conducted yearly since 2009. The timing of the survey has varied from year to year in order to find the optimum season for estimating the size of the vendace stock.

During the first four years (2009-2012) the survey was conducted approximately one week before the start of trawl fishing season (Fig. 2). This decision was made due to difficulties of finding an appropriate survey vessel within the budget during the vendace fishing season and based on the information about the behavior of vendace obtained from the trawl fishermen. It was assumed that during that time there is little or no migration of vendace in the Norrbotten Archipelago providing estimates that represent a good ‘snapshot’ of the actual vendace stock. However, the survey results showed that due to the fish migrations the vertical distribution of the fish were unsuitable to be detected by the acoustics. Thus in conclusion, based on the actual survey results (see Results) the period one week before the start of the trawl fishing season was not considered the most suitable time to estimate the size of the vendace stock. Therefore in 2013 and 2014 the survey was performed after the trawl fishing season (Fig. 2) assuming that pre-spawning vendace aggregations could be detected easiest just before the start of the spawning season. The survey conducted after the trawl fishing season revealed that the survey was partly overlapping with the vendace spawning season. So an extra effort and funds were allocated to the survey project in 2015 to find a suitable boat to conduct the survey during the trawl fishing season (i.e. before the spawning season). In 2015 the survey was undertaken during one week in the middle of October (Fig. 2).

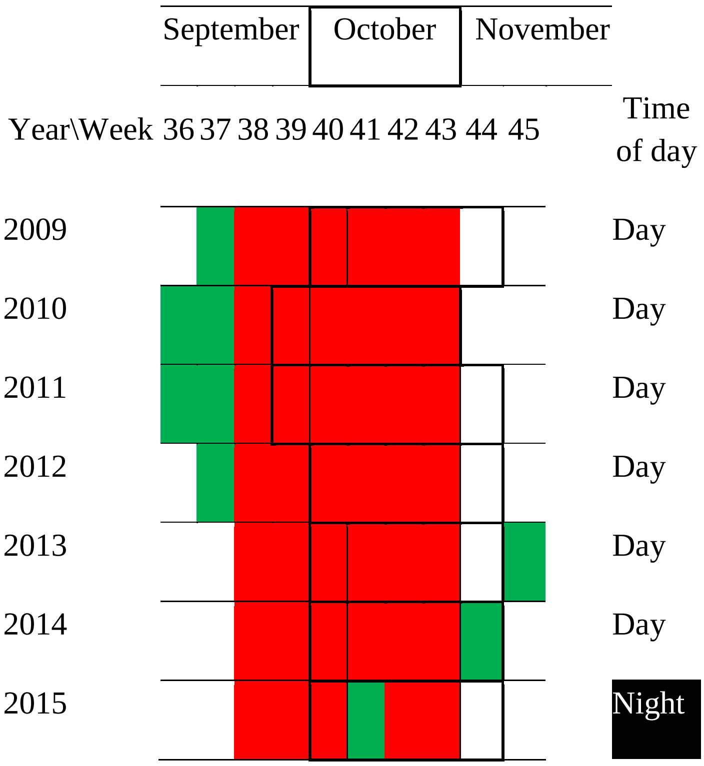

Figure 2. Timing of the vendace trawl fishing season (in red) and the timing of the survey (in green) during 2009 to 2015.

The acoustic investigations were performed at day time during the years 2009-2014 when commercial vendace bottom trawlers were chartered (Fig. 2). This was due to the fact that vendace can be caught by a bottom trawl net only in daylight when they are aggregated close to the bottom. In 2015 a small scientific pelagic trawl net was used on a chartered commercial herring trawler and therefore the survey was conducted at night time, when vendace are more dispersed above the bottom and easier to catch with the pelagic gear.

Survey design and data collection

In order to meet the survey objectives the survey has been performed by using the mobile vertical acoustic-trawl survey method including the following components:

- systematic areal acoustic survey with zig-zag design transect to collect acoustic data covering the areas where the fish are
- trawling to collect the biological data in order to determine the fish species composition and stock structure
- environmental data collection for acoustic calculations and to explain distribution of fish which depends highly on salinity and temperature

Chartered fishing vessels have been used as a survey platform for the collection of data. A suitable platform for survey is a 12-20 m long vessel with experienced crew, which is able to perform trawl hauls and navigate in the shallow archipelago sea. Survey was initiated by hiring local commercial vendace trawlers with professional vendace fishermen to ensure suitable trawl net, skills and knowledge about vendace necessary to carry out the survey. In 2015 a commercial herring trawler was chartered from Gävle to perform the survey during the vendace trawl fishing season, because no commercial vendace trawlers were available for a reasonable price during the fishing season in the actual survey area.

Acoustic data

The basic tool in fisheries acoustics is the scientific echosounder. This instrument sends out sounds down into the water column and receives echoes from objects in the water. Echoes, reflected from the fish school and the seabed, are displayed on the echogram. The intensity of the echoes from the fish schools is determined by echo integration and measured as the Nautical Area Scattering Coefficient (NASC) which is then used to compute stock biomass and numbers. For more detailed information on the acoustic and data analysis please see Appendix 1.2.

Biological data

The collection of fish samples has been done to determine the species composition, length distributions and mean weight of fish species detected by the echosounder, and to collect vendace specimens for auxiliary information (e.g., age, maturity and sex).

In 2009-2014 all fish samples were taken using a commercial vendace bottom pair-trawl, for which the selection panel was removed. The vertical opening of the trawl net was 5 m and the stretched mesh size in the cod-end 13 mm. In

2015 a small scientific pelagic trawl net (with 5 m vertical opening and 10 mm stretched mesh size in the cod-end) was tested, but no valid trawl hauls were obtained due to technical problems. Therefore, commercial vendace trawl catches from the same area and time were used for 2015 trawl samples.

Based on the commercial fisheries areas, twelve trawl hauls were selected annually in the same areas (bays) that evenly covered the survey area (Fig. 1).

Total catch from the trawls was sorted into species, and the corresponding weight per species was registered to determine the species composition of the fish. The weight of the sub-sample and the total weight per species in the sub-sample were registered. For more details on the sampling of biological data please see appendix 1.3.

Catch per unit effort (CPUE) is commonly used as an indirect measure of the abundance of a target species. In this study CPUE is expressed as catch (in kg) of a species in the trawl haul per 1 hour fishing.

Environmental data

Temperature and salinity were measured before the start of the survey and after each trawl haul to calculate the sound speed and attenuation (acoustic absorption coefficient) values in the echo sounder settings for the acoustics. Temperature and salinity data were also used to understand the behavior of vendace due to changes in environmental factors. Echo integration method (Simmonds and MacLennan 2005) was used to provide acoustic abundance and biomass estimates of fish. For detailed information on the data analysis please see appendix 1.4.

Results

NASC, CPUE and catch compositions

Mean Nautical Area Scattering Coefficient (NASC) and mean catch per unit effort (CPUE) values from the trawl hauls of acoustic surveys are shown for each year in figure 3. The highest NASC values were measured in 2013 and 2015. The highest mean total trawl catches were caught in the 2013 survey (due to technical problems haul data are missing from the survey in 2015). The timing of the survey has been different in different years. Therefore, CPUE and NASC values cannot be compared over time. However, high correlation between mean total trawl catches (CPUE kg/h) and mean Nautical

Area Scattering Coefficient (NASC $m^2/n.mi^2$) values from the surveys during 2009-2014 reflects the annual changes in the quantities of fish in the survey area (Fig. 4). This high correlation supports the assumption that the acoustic survey is a suitable method for the estimation of the quantity of fish in the Norrbotten Archipelago.

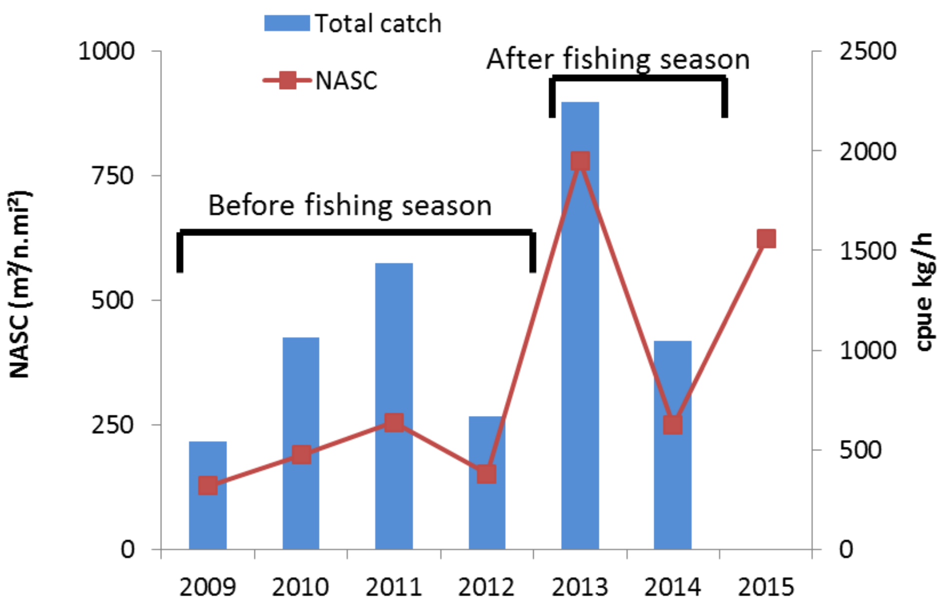

Figure 3. Mean total trawl catches (CPUE kg/h) (bars) and mean Nautical Area Scattering Coefficient (NASC) values ($m^2/n.mi^2$) (red line) from acoustic surveys during 2009-2015. The survey time differs from year to year: 2009 till 2012 surveys were conducted before, 2013 and 2014 after and in 2015 during the trawl fishing season. No valid haul data are available from survey for year 2015.

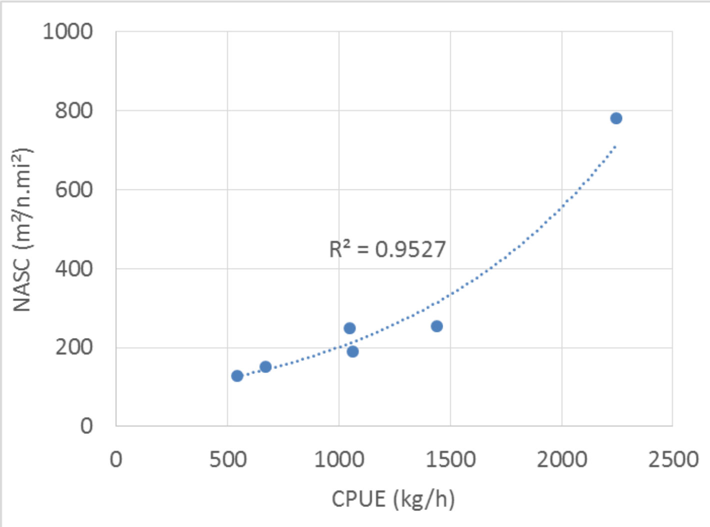

Figure 4. Correlation between the mean total trawl catches (CPUE kg/h) and mean Nautical Area Scattering Coefficient (NASC) values ($m^2/n.mi^2$) from acoustic surveys during 2009-2014.

For information on the proportion and catch per unit effort values of vendace and other species caught in the survey during 2009 to 2015 please see appendix 1.5. The results on the other species give us valuable knowledge on the state of species such as herring, whitefish, smelt and perch but vendace dominated the catches in almost all of the survey times (Fig. 1A, Appendix 1.5).

Abundance and biomass estimates

The overall results of the survey time series are reflecting our strive to find the best timing of the survey. During the first three years of the survey (before the fishing) the vendace spawning stock biomass estimates showed an increasing trend and were in line with the results of the stock assessment model (Pope's cohort analysis), which was the only analytical stock assessment tool used at that time (Fig. 5). However, in 2012, the estimates from the survey were about half the previous year's estimates and were not in accordance with the assessment model results (Fig. 5). The vendace abundance at age estimates show that the abundance of different year-classes has varied from year to year and it is not possible to follow the age classes from one year to the next (Fig.6 and appendix 1.5, Table 1). If we compare the abundance of different year-classes over the years, it also suggests that the abundance of vendace in the younger age groups (0 and 1) has been underestimated in the survey during the years 2009-2012, when the survey was conducted before the fishing season in September. The survey results indicate that September is not the optimal time for estimating the size of the vendace stock, because the share of the pre-spawning vendace aggregations that migrate into the deeper parts of the archipelago show high variation from year to year. Therefore in 2013 and 2014 the survey was moved to a later occasion and was performed first after the trawl fishing season (Fig. 2).

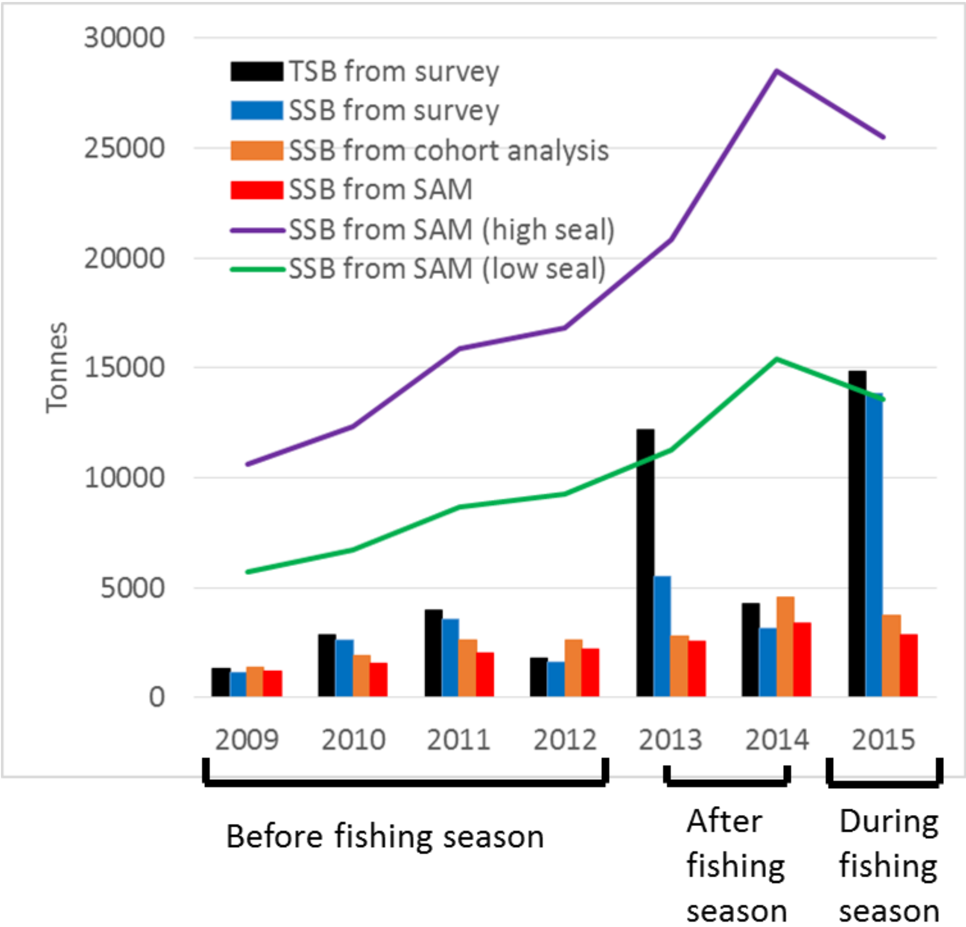

Figure 5. Total stock biomass (TSB) and spawning stock biomass (SSB) of vendace hydroacoustic estimates (ton) in the Norrbotten archipelago in comparison with SSB estimates from two stock assessment methods (Bergenius, 2016): Pope's cohort analysis and State-space Assessment Model (SAM). Pope's cohort analysis and one SAM run has been made without taking into account vendace predation by seals. Two additional SAM runs have been made where vendace predation by seals was taken into account (with high and low seal abundance estimations).

In 2013 the spawning had started earlier than expected due to frost conditions and most of the sexually mature fish that we observed in the trawl samples were already spent and young of the year vendace dominated in the survey catches by 72% (Fig. 6, appendix 1.5 Table 1). The abundance and biomass estimates for vendace from the survey were unexpectedly low in 2014 compared to values from the previous year as 70% of the sexually mature fish that we observed in the trawl samples were spent indicating an ongoing spawning (Figure 5 and 6). The first exploratory stock assessment run was made with State-space Assessment Model (SAM) in 2014 produced similar results to Pope's cohort analysis, but the survey estimates for the spawning stock biomass in 2013 were twice as high (Fig. 5). This indicated that the stock assessment models, which do not take into account vendace predation by seals, are probably underestimating the size of the stock. Also the result revealed that the vendace spawning time is overlapping with the survey time directly after trawl fishing season and is thus not either an optimal time to get a good 'snapshot' of the status of the whole vendace stock. Postponing the survey even later to late November is considered too risky due to possible ice cover. Therefore, extra effort and funds were allocated to the project in 2015 to find a suitable boat for the survey to take place during the trawl fishing season.

In 2016, two exploratory stock assessment runs were made with SAM where, for first time, also vendace predation by seals was taken into account (one run with high and the other with low seal abundance estimations). These runs produced much higher estimates for vendace stock compared with the previous assessments (Fig. 5). But, the assessment models still have high uncertainties in the estimated level of the vendace stock biomass in the Bothnian Bay.

The timing of the last years of surveys (2013-2015) shows that the survey was able to follow the big cohort born in 2013 (Fig. 6C, Appendix 1.5, Table 1). The ability to follow cohorts and strong recruitment events is crucial for surveys to be used as tuning in stock assessment models.

Due to the limitations of hydroacoustic method, it is relatively difficult to overestimate the amount of the fish. The spawning stock biomass estimate from 2015 (mid-October) survey were the highest during the investigation period and it coincided with the results of the SAM run with low seal abundance (Fig. 5). This supports that the optimal timing of the survey would be during the fisheries season in mid-October. The abundance of the young of the year vendace was however, underestimated by the survey in 2015.

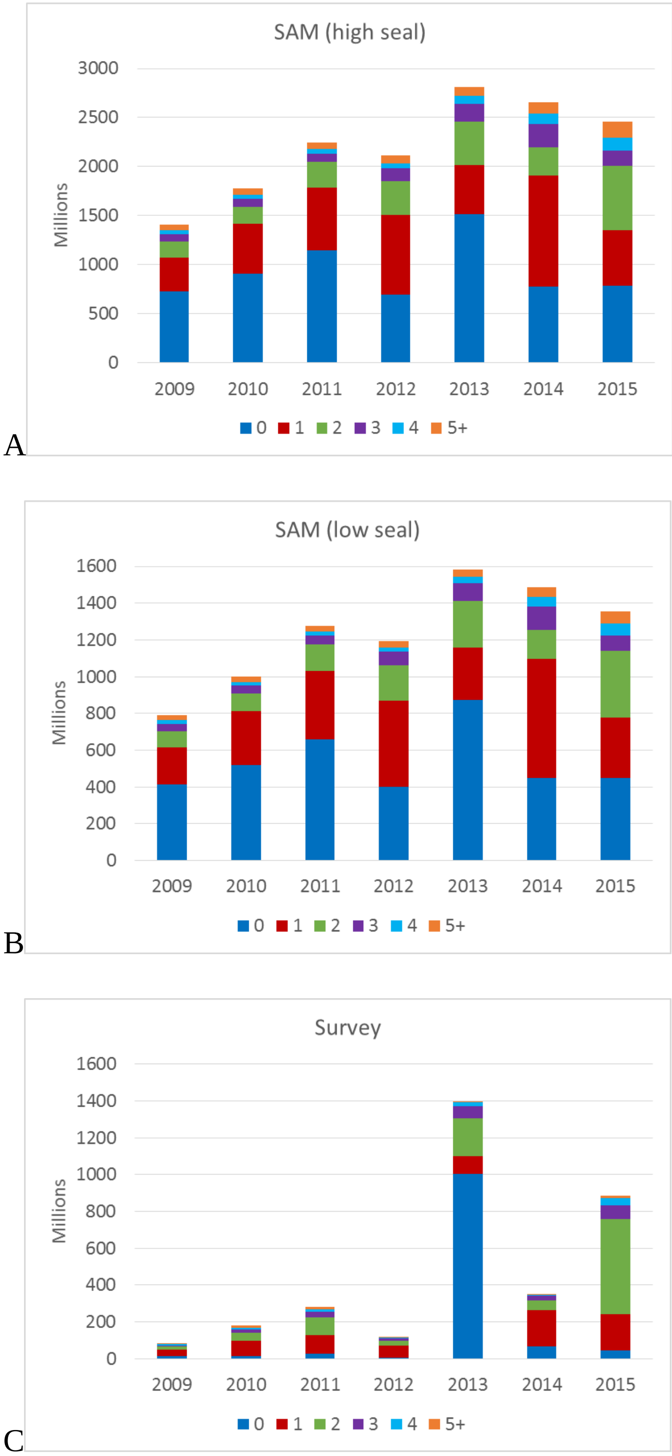

Figure 6. Abundance (mln.) of vendace at age estimated hydroacoustically from the survey (C) in the Norrbotten archipelago in comparison with the estimates of State-space Assessment Model (SAM) (Bergenius, 2016) where vendace predation by seals was taken into account (with high (A) and low (B) seal abundance estimations). Notice the different scale on the SAM (high seal) plot.

Recruitment

The bottom trawl's selection panels (grid) used by the commercial trawlers does not capture the vendace recruits (young of the year fish) in proportion to their abundance. Since the vendace fishery is to a large extent a recruit driven fishery (a strong year class is structuring the fishery several years later), estimates of the strength of a year class would provide key information on the forthcoming years abundance of vendace and the fishery opportunities. One of the major advantages of an acoustic survey is the ability to capture the recruits (0+). Unfortunately; survey abundance estimates of vendace recruitment were low for most of the years. However in 2013 (when survey was performed in November) the survey was able to capture the large year class going into the fishery, and the same cohort could be followed even in the forthcoming years (Fig. 6 and 7).The survey estimates for recruitment from 2013 were comparable with SAM assessment results (Fig. 7).

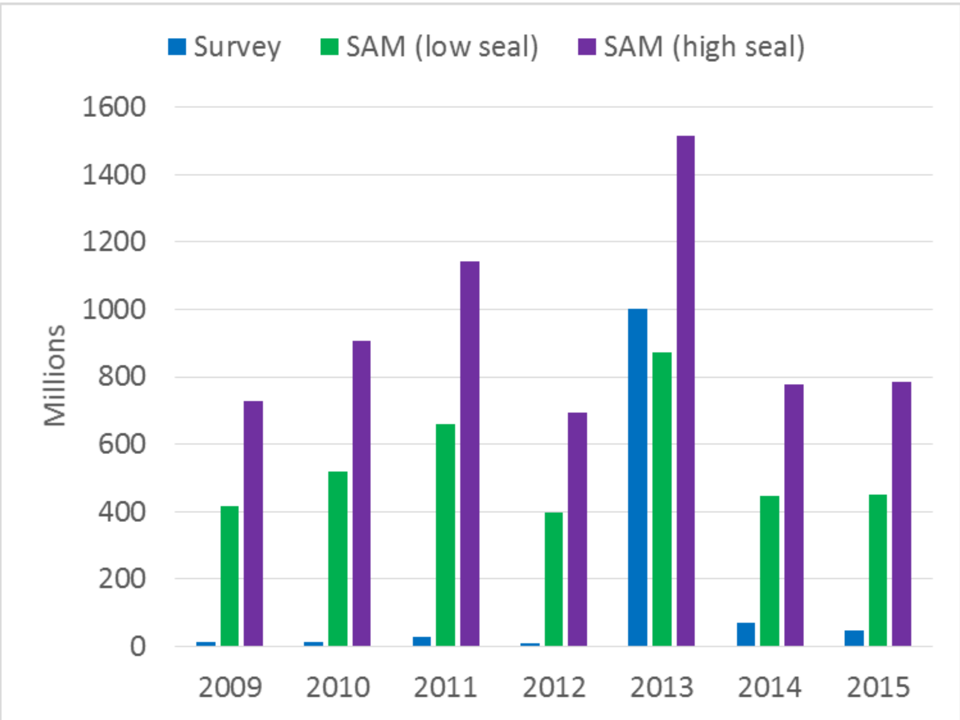

Figure 7. Abundance (in millions) of the young of the year vendace estimated hydroacoustically in the Norrbotten archipelago in comparison with the estimates of State-space Assessment Model (SAM) (Bergenius, 2016) where vendace predation by seals was taken into account (with high and low seal abundance estimations).

Age composition

The age composition of vendace in the survey hauls was similar for all years with exception of year 2013 when there was a high proportion of age 0 individuals, capturing the strong recruitment that year (Fig. 8). Even though the timing of the surveys has varied during the years, the ability to follow the large recruitment of 2013 and its proceeding as one year old in 2014 shows that the timing of the survey after the fishery season is a suitable time to get a good estimate of the recruitments (Fig. 8).

The age composition of vendace from the survey catches and the commercial trawl catches followed a similar pattern (Fig. 8 and 9). The proportion of age 0 individuals in the survey hauls was lower than that in the commercial trawl catches before the fishing season (in 2009-2012), although the fishermen have a selection panel in their trawl nets to minimize the bycatch of immature (<12.5 cm) vendace. In the catches after the trawl fishing season (2013 and 2014), the proportion of age 0 individuals in the survey hauls was much higher than that in the commercial trawl catches (Fig. 8 and 9). Age 0 vendace is recruited abundantly into the trawl catches after week 42 (end of the fishing season) probably due to the changes in vendace spatial distribution (migrations) as the young of the year vendace descend to the deeper areas, when the dense spawning shoals enter the shallow coastal waters (Fig. 10).

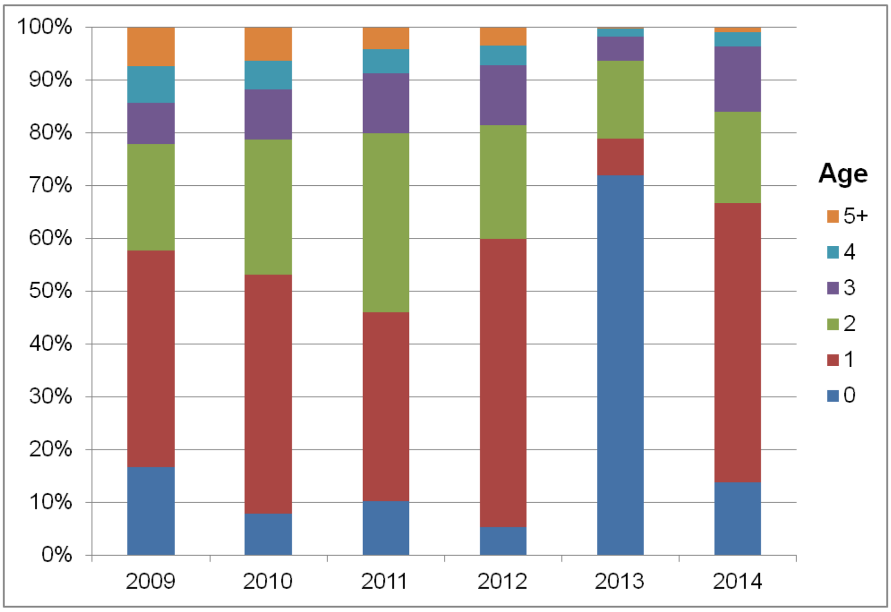

Figure 8. Age composition (%) of vendace in the survey catches in 2009-2014. No suitable data are available for 2015.

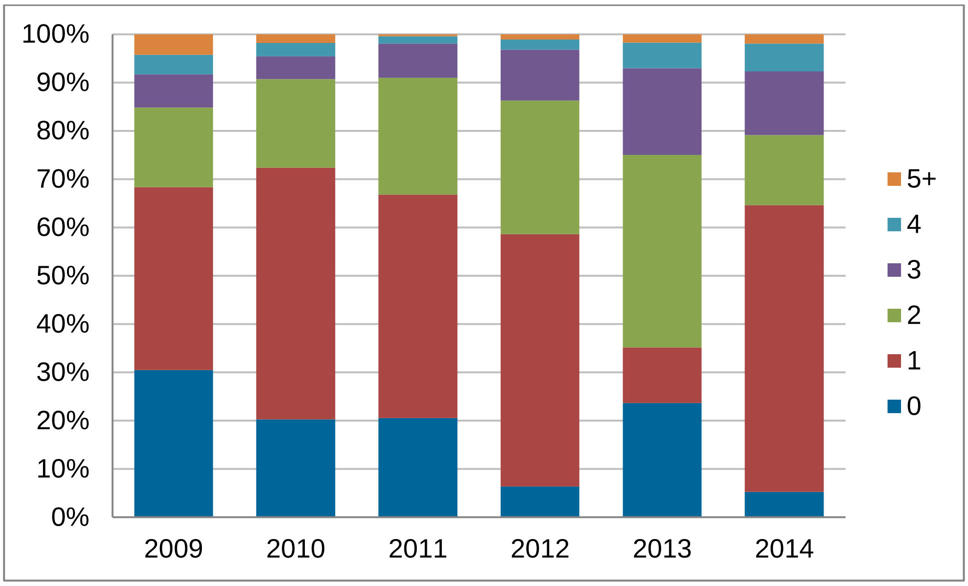

Figure 9. Age composition (%) of vendace in the commercial trawl catches 2009-2014.

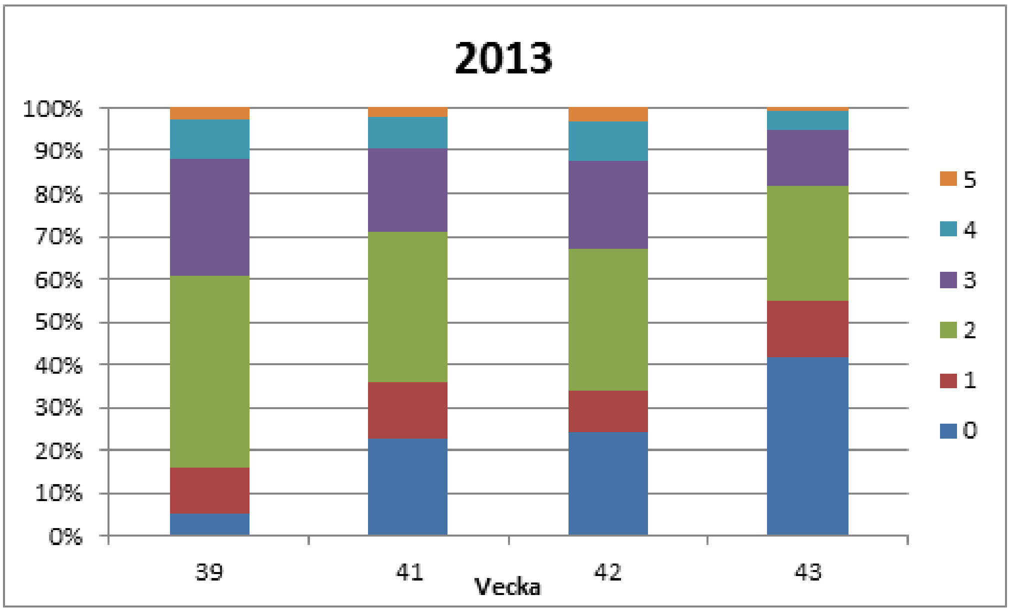

Figure 10. Dynamics of the vendace age composition (%) weeks 39-43 in the commercial trawl catches in 2013.

Vendace behavior

Vendace survey covers mainly coastal areas with mean depth between 10 and 30 meters. Shallower and deeper areas are covered to a lesser extent. Therefore, the survey estimates are significantly influenced by the vendace behavior (horizontal and vertical distribution). Usually the highest densities of vendace have been recorded in the areas with the mean depth between 10 and 20 meters. In 2009 and 2012, when the lowest biomass estimates of vendace were measured in the survey, the highest densities were recorded in the shallower areas.

Vendace in the Bothnian Bay have very complex behavior (compared with vendace in lakes) and the different timing of the survey during the years has provided important knowledge on their behavior. Vertical and horizontal distribution is changing remarkably during the year, and this makes it difficult to detect the fish with hydroacoustics. But now, with the knowledge from the fishermen combined with information from the acoustic survey, we have valuable expertise in variation of the horizontal and vertical distribution of the vendace stock due to changes in water temperature, diel conditions and life history. This knowledge is crucial for the interpretation of the results from the survey. Our results suggest that the survey before the fisheries season (2009-2012) did not cover the whole stock due to high migration of vendace and does not provide good estimates for actual state of the stock. A suitable time to get reliable estimates for the adult stock would be during the fisheries season in mid-October. The night time vendace distribution in October (temperature 7-9 C°), when pre-spawning vendace are dispersed close to the bottom, mainly in the deeper parts of the archipelago, seem to result in most reliable estimates of the status of the vendace spawning stock (Appendix 1.10, Fig. 6A: Schema E). During this time the age zero vendace is essentially remaining close to the water surface in the shallow coastal areas and vendace spawning in the rivers has started (Appendix 1.10, Fig. 6A: Schema E). This means that vendace river spawning populations as well as the newly recruited year-class would be excluded from the stock estimates.

Knowledge on the abundance of vendace recruitment is essential to predict the following year's catches. The survey that was conducted after the fisheries season (in November) provided good estimates of the recruits, but on the other hand the adult vendace were underestimated in this survey due to overlap with spawning time. An additional survey would be needed in November to target the recruitment of vendace, in order to improve the predictions for the following year. However we would need 3-5 more years of recruitment data to be able to use them in forecast models of stock assessment. Furthermore there are risks to keep the survey as late as November as ice cover could arrive early in some years and low water temperature can affect the behavior of vendace.

The current data used in the stock assessment of vendace in the Bothnian Bay include catch data (landings) and data from a commercial tuning fleet (extended logbook data from vessels participating in the fishery). However, there are some intrinsic problems when a commercial tuning fleet is used in the assessment. Firstly, as the commercial tuning fleet data are also used in the catch matrix there is a “circular argument” that is hard to overlook (commercial catch data are tuned with the commercial catch data in the state-space assessment model SAM). Secondly, commercial fishery CPUE is usually higher and more stable than the fishery independent CPUE, since fishermen are able to target hot spots where fish aggregate even if the stock size is decreasing. Thirdly, as the fishing fleet is maximizing their gear for large catches, there is a need to standardise the tuning fleet according to increased effectiveness of the fishing fleet. Even though it is not reliable to use a commercial tuning fleet in the stock assessment of vendace, in cases where fishery independent source of information is totally lacking, using a commercial tuning fleet is the only way to perform an assessment. However, it is crucial to have a fishery independent survey that we could rely on for good estimates of the stock status of vendace in the Bothnian Bay.

The previous survey years have been exploratory and aimed to investigate the best timing for the vendace survey to be used in the stock assessment. During the past seven years the surveys have been conducted in different seasons and times of the day. The current stock assessment model (SAM, state-space assessment model) has some limitations in handling this type of fragmented data in a proper way which is why we have so far not been able to use the acoustic surveys in the actual assessment. However, recently a new assessment model, named Stock Synthesis (SS3), was introduced for the vendace assessment. This model is a flexible stock assessment tool that can use fragmented data such as the survey data from the past seven years. In the final run of the SS3 model including all the years of the fishery independent survey was used, and it made the assessment perform better.

Since the behavior of vendace is complex and their distribution is dependent on temperature and salinity the survey may miss out on the vendace in years with very different environmental conditions. The vendace horizontal distribution is more stable in the autumn at water temperatures 7-9 degrees to get a good estimate of the vendace spawning stock with acoustics. For the acoustic estimations of vendace night time is the best diel timing, when the fish are not too close to the bottom and are most dispersed. But it is very difficult to collect biological fish samples during the night time as vendace is then more dispersed above the bottom, and do not enter into a bottom trawl net. At the same time, they are still too close to the bottom to catch them successfully with a pelagic trawl gear. Because of the shallowness and roughness of the sea bed, there is a high risk to tear the trawl net asunder against the bottom. The best time for trawling the biological samples is the daylight, when the vendace is aggregated on the bottom and can be easily caught by a bottom trawling.

Conclusions

All the years that the survey has been conducted has aimed at finding the most suitable time to estimate the state of the vendace stock. Thus all the years provide support on the final decision of the timing and the suitability of the survey method that should be used for the vendace in the Bothnian Bay. The SS3 model for vendace is still in a premature state and is currently under work, but it is promising and would be a strong candidate for the future assessment model for vendace. Even when SS3 is able to use temporally fragmented data, the best model performance and most reliable stock estimates are achieved when the timing of the survey is kept constant and conducted during the optimal season during the fishery in mid-October as it has been done in 2015. To further improve the predictions for the state of the coming year vendace stock the survey should also be conducted in November (as done in 2013) when the abundance of vendace recruitment can be estimated. However, November is risky time for the survey since ice cover could arrive early in cold years and low water temperatures will affect vendace behavior.

The total catches of vendace fishery has shown increasing trend during the past years and is currently doing well. However, if in the future there would be a decline in the fishery, it is important to have an ongoing fishery independent survey to be able to follow and understand the reasons behind any drop in the vendace fishery.

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For the completion of this report the following people from SLU Aqua have contributed:
Zeynep Hekim, researcher and project leader,
Olavi Kaljuste, research assistant and survey leader,
Mikaela Bergenius and Johan Lövgren, researchers.

Appendix

1.1 Commercial fisheries

Pair trawling is a fishing activity carried out by two boats, with one pulling each towing cable. As the mouth of the net is kept open by the lateral pull of the individual vessels, otter boards are not required. Otter boards are used in trawling to keep the mouth of the trawl net open.

1.2 Acoustic data

The acoustic data were collected using a 70 kHz Simrad EY60 portable scientific echo sounder system with down looking ES70-7C transducer (echo sounder). The transducer was mounted with a pole to the board of the vessel at 1.8 m depth. Vessel speed during the collection of acoustic data was approximately 7 knots. The following settings of the hydroacoustic equipment were used: pulse length (duration) - 0.128 ms, sample interval - 0.032 ms, pulse rate (interval) - 0.3 s, range sampled - 50 m, transmit power - 400 W.

The survey transects were divided into 0.2 n.mi. elementary sampling distance units (ESDU), where acoustic measurements from the 5 m depth to the bottom are averaged to give one value of nautical area scattering coefficient (NASC) (Simmonds and MacLennan, 2005). However, due to the blind zone (Simmonds and MacLennan, 2005) fish that are very close (0-15 cm) to the bottom are not able to be seen.

Acoustic measurements from the 5 m depth (due to the transducer depth and near-field effect (Simmonds and MacLennan, 2005)) to the bottom are used for the calculation of vendace stock size. However, due to the blind zone we are not able to see the fish very close to the bottom. Therefore, the amount of the vendace aggregations that are located in the shallow coastal areas (depth below 10 m), close to the surface (0-5 m) and close to the bottom (0-15 cm) cannot be estimated by the survey.

1.3 Biological Data

The trawling time varied between 5 and 30 minutes (mainly between 5 and 10 min.) at speed 2.8-3.3 knots depending on the density of fish aggregations observed on the echogram. Fish catches were localized on the depth (depth to the sea bottom) ranged from 12 to 28 m (mainly between 15 and 20 m). Total catch from the trawls was sorted into species in case of small catches (<70 kg), and the corresponding weight per species was registered to determine the species composition of the fish. In case of large homogenous catches a sub-sample of ~30 kg was taken from each haul and identified and sorted by species.

In case of heterogeneous large catches consisting of a mixture of similar looking fishes (vendace, herring, smelt and small whitefish) and few different looking fishes (large whitefish, perch, ruff, etc.), the total catch was partitioned into the part of different looking fishes and that of the mixture of similar looking fishes. From the mixture of similar looking fishes, a sub-sample of ~30 kg was taken. The total weight per species for the part of the different looking fishes and the total weight of the sub-sample of mixed similar looking fishes were registered.

Length distributions were recorded for all caught fish species. For vendace, herring and sprat sub-samples containing at least 200 specimens per species (if possible) were taken from each haul to determine the length distribution by 0.5-cm length-classes. For vendace also the mean weights of individuals in each length-class were recorded. For all other fish species, at least 50 specimens per species (if possible) were measured by 1-cm length-classes.

Additionally, biological samples were collected for age, sex and maturity stage determination of vendace. The following sampling was used per haul and per 0.5 cm length-class:

• 5 specimens per length-class for fish <15 cm

• all the measured specimens per length-class for fish ≥15 cm

1.4 Data analysis

Echo integration method (Simmonds and MacLennan 2005) was used to provide acoustic abundance and biomass estimates.

The target species (vendace) is usually distributed together with other species, which makes it impossible to allocate the integrator readings to a single species. Therefore, species allocation is based entirely upon trawl catch composition.

The density of fish (number of fish per 1 n.mi.^{2}) was estimated as the product of the mean measured nautical area scattering coefficient (NASC) value divided by the mean cross section (sigma) (Simmonds and MacLennan 2005) of all fishes in the nearest haul. The mean cross section value for each haul was calculated using the following formula

$$< \sigma > = \sum_i f_i \sum_j f_{ij} 4\pi \cdot 10^{a_i/10} \cdot L_j^{b_i/10}$$

where: a_i and b_i are constants (CEN 2014, Didrikas & Hansson, 2004) for the i^{th} species, L_j is the midpoint of the j^{th} length-class (cm), f_i is the mean frequency of species i and f_{ij} is the mean frequency of length-class j for the i^{th} species in the haul.

The density of different fish species (number of fish per 1 n.mi.^{2}) was separated from the total fish density according to the species composition of the corresponding trawl catch composition from that haul. The biomass of different fish species (tonnes per 1 n.mi.^{2}) was calculated by multiplying the abundance (density) values with the mean weight of that species in the corresponding trawl haul. Based on these density estimates, the average abundance (density) and biomass of fish species was calculated for the total survey area.

The total number and biomass of a vendace in the survey area was estimated based on the average density of vendace at depths <30 m, which is preferred habitat of vendace pre-spawning schools. Vendace spawning stock biomass (SSB) was separated from the total biomass estimations based on the maturity key obtained from the biological analyses.

1.5 Proportion and cpue of vendace and other species in the survey

Vendace dominated the annual survey catches by 40-90% (Fig. 1). Year 2012 was the only exception when the share of vendace was the lowest (37%) in the survey which was conducted before the trawl fishing season. Herring and whitefish were the next dominant species with a presence of about 11-22% of the average catch before the trawl fishing season and 1-3% after the trawl fishing season (Fig. 1). The highest CPUE of vendace in the survey catches was in 2013 (Fig. 2). Due to technical problems there are no valid trawl catch data available from year 2015 survey. Herring, whitefish and also smelt CPUE in the survey trawl catches was much lower in 2013-2014, when surveys were conducted after the trawl fishing season (Fig. 2).

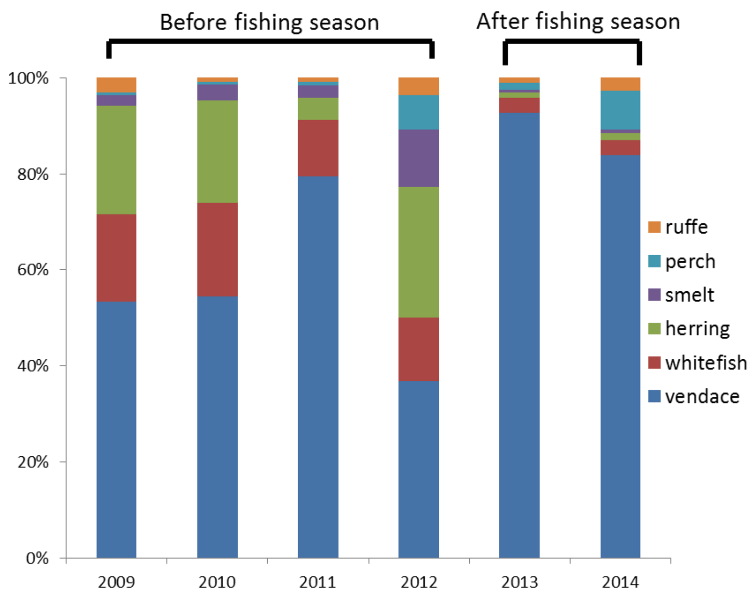


Figure 1A. The mean proportion (%) of different species by weight in the survey trawl catches for years 2009-2014. The survey time differs from year to year: 2009 till 2012 surveys were conducted before and 2013 and 2014 after the trawl fishing season.

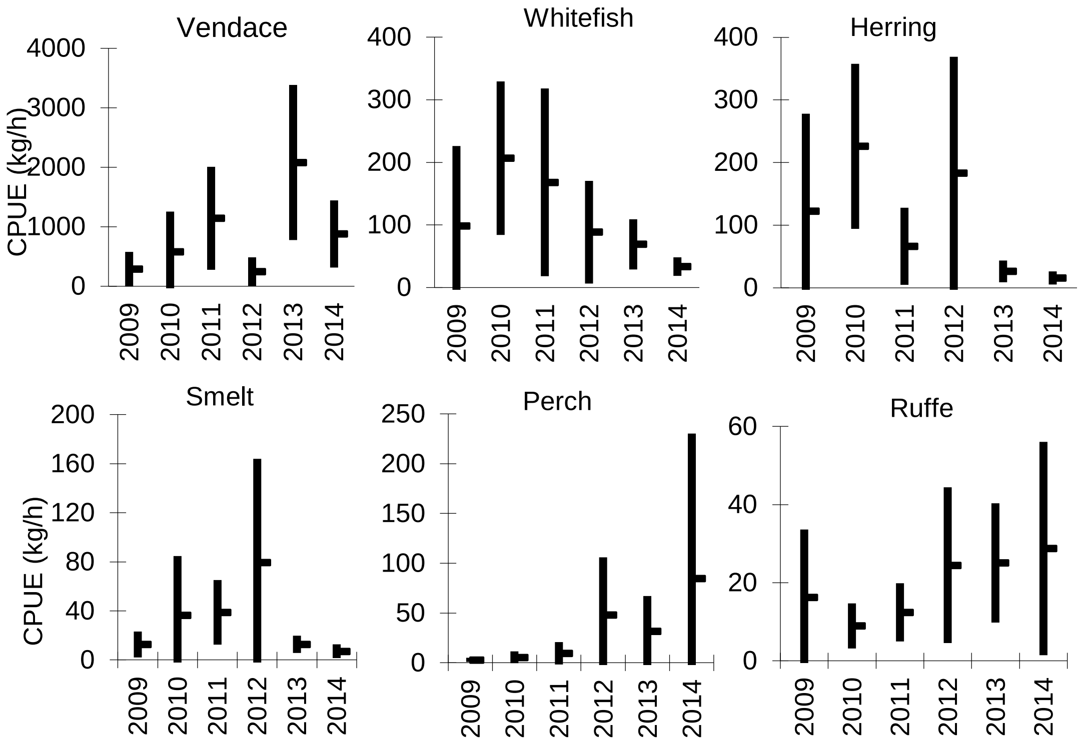


Figure 2A. The mean CPUE (kg/h) of vendace, whitefish, herring, smelt, perch and ruffe caught in the survey during 2009-2014 with 95% confidence limits. The survey time differs from year to year: 2009 till 2012 surveys were conducted before and 2013–2014 after the trawl fishing season. Notice the different scales on the plots.

Table 1. Vendace abundance (mln.) at age estimated by hydroacoustics in the Bothnian Bay.

Age	Year 2009	2010	2011	2012	2013	2014	2015
0	14	14	29	8	1003	69	47
1	35	82	101	62	98	196	196
2	17	46	96	27	205	49	516
3	7	17	32	14	65	28	73
4	6	10	13	5	20	6	41
5	4	7	7	1	3	2	6
6	2	2	3	2	0	0	4
7	1	1	1	1	0	0	2
8+	0	1	0	0	0	0	0
Total	85	181	282	120	1395	351	886

1.6 Length structure

The Kolmigorov-Smirnov test was applied annually to the observed length distributions of vendace in the survey hauls. The aim was to identify whether the structure of the whole vendace stock was homogenous by area or it included significantly different length clusters. There were 3 different length clusters (homogenous regions) in most years. In general the hauls with higher share of smaller (young of the year old) and larger individuals differed by clusters from the other hauls indicating that they inhabited different areas. In 2009-2011 these homogenous regions were distributed rather similar way, while there were no obvious inter-annual regularities in the formation of these clusters in 2012-2014. Then the hauls belonging to the same cluster were geographically distant from each other.

1.7 Mean weight

Dynamics of the vendace mean weight in the survey hauls is presented in Figure 3. The mean weight decreased somewhat in all age groups in 2009-2011 and increased slightly again for sexually mature fish in 2012, when the surveys were conducted before the trawl fishing season. The mean weight of adult vendace in the survey hauls was lower in 2013 and 2014, when surveys were performed after the trawl fishing season and about 70% of the sexually mature fish was spent (Fig. 3). Vendace individuals loose approximately 20-30% of their body weight during the spawning, compared to the pre-spawning weight.

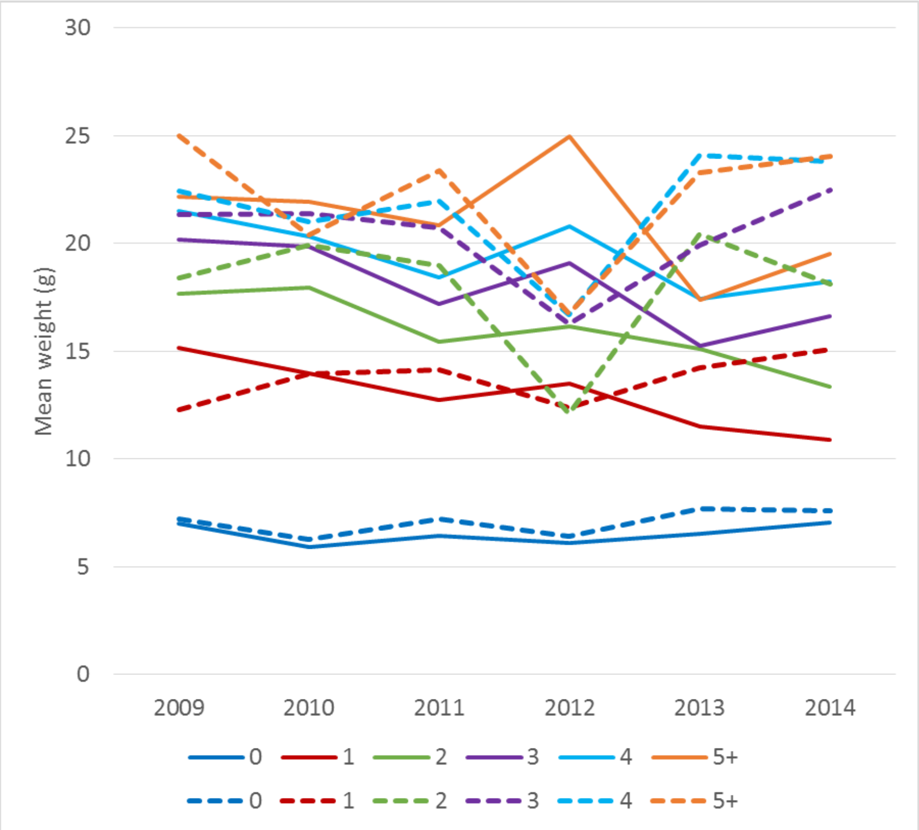


Figure 3A. Comparison of the vendace mean weight at age in the survey hauls (solid lines) and in the commercial trawl catches (dashed lines) (Bergenius, 2016) in 2009-2014.

1.8 Sexual maturity

Sexual maturity estimates from the survey and commercial trawl samples do not differ significantly. Biological samples from survey were used in previous years (2009-2011) as additional data source for the estimation of sexual maturity at age for stock assessment purpose.

1.9 Vendace distribution

In 2009-2012, when the surveys were conducted in September, dense vendace pre-spawning shoals were noticed in the mouth of the river Lule älv (Figure 4).

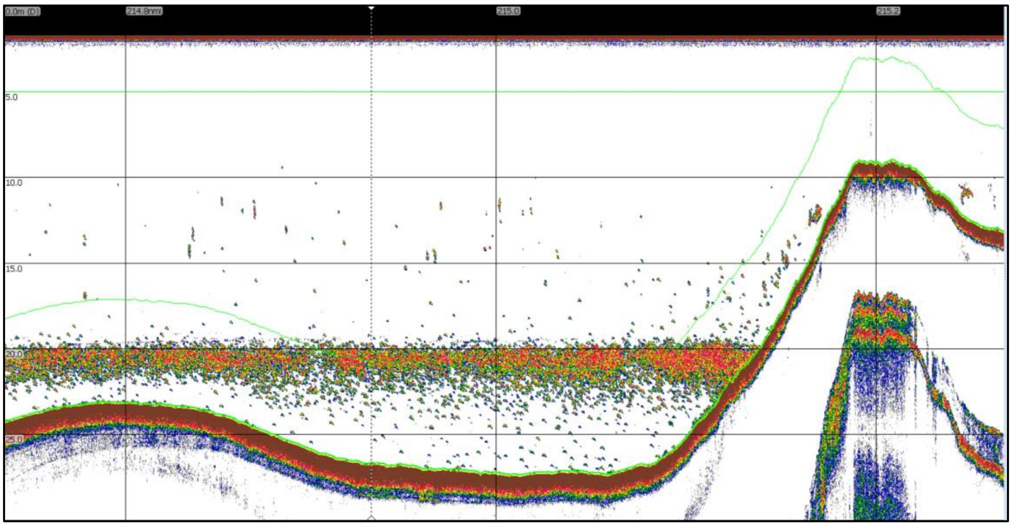


Figure 4A. Typical echogram showing a pre-spawning shoal of the vendace in the mouth of the river Lule älv (at dawn) in September 2011. Lower green line is the sea bottom contour, colored dots and patches are the vendace individuals and aggregations, respectively.

Figure 5 illustrates the diurnal changes in the vertical distribution of the vendace in the autumn. It reveals that during the night time is vendace usually dispersed above the bottom. At dawn, vendace is migrating closer to the bottom and starts to aggregate. In daylight, vendace aggregations are situated densely near the bottom and at dusk they scatter again above the bottom.

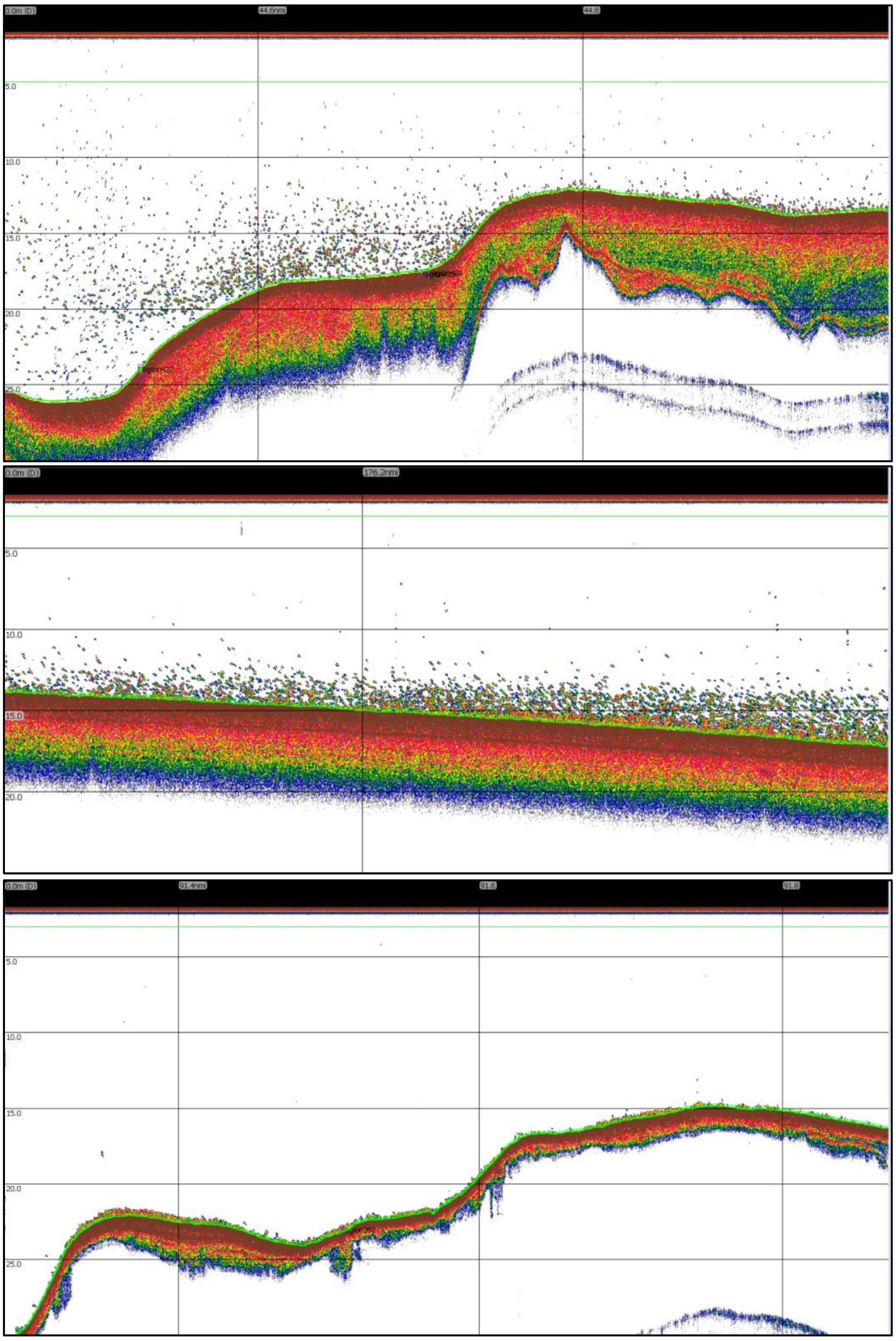


Figure 5A. Typical echograms showing the diurnal differences in vertical distribution of the vendace in acoustic surveys. Lower green line is the sea bottom contour, colored dots and patches are the vendace individuals and aggregations, respectively. Above: vendace is distributed dispersed above the bottom during the night time (in October 2015). Middle: scattered vendace close to the bottom has started to aggregate during the dawn (in November 2013). Below: vendace aggregations are situated densely near the bottom during the daylight time (in November 2013).

1.10 Vendace behaviour

Table 2 shows how the different timing of the survey has provided important knowledge on the behavior of the vendace populations in Norrbotten Archipelago

Table 2. The behavior and location of vendace depending on the time (day or night) and water temperature during the survey years 2009-2015. The reference to the drawings for the behavior and location of the vendace shown in Figure 16 is also included in the table.

Year	2009	2010	2011	2012	2013	2014	2015
Survey time	07-12 September	11-15 September	09-13 September	10-13 September	04-08 November	27-31 October	12-17 October
Diurnal timing	Day	Day	Day	Day	Day	Day	Night
Water temperature	13-15°C	10-14°C	10-15°C	11-14°C	3-5°C	5-6°C	6-8°C
Shoaling behavior	Pre-spawning	Pre-spawning	Pre-spawning	Pre-spawning	Spawning/ after spawning	Spawning/ after spawning	Pre-spawning
Vertical distribution	Partly migrated to the bottom	Partly migrated to the bottom	Partly migrated to the bottom	Partly migrated to the bottom	Concentrated on the bottom	Concentrated on the bottom	Scattered close to the bottom
Horizontal distribution	Mainly in shallow (<20 m) areas	Mainly in deeper (10-30 m) areas	Mainly in deeper (10-20 m) areas	Mainly in shallow (<20 m) areas	Mainly in deeper (10-20 m) areas	Mainly in deeper (10-20 m) areas	Mainly in deeper (10-20 m) areas
Drawing reference	B	C	C	B	H/I	H	E

The sketches in Figure 15 describe the typical distribution patterns of vendace, which are based on the information gained from the survey, catch statistics and fishermen.

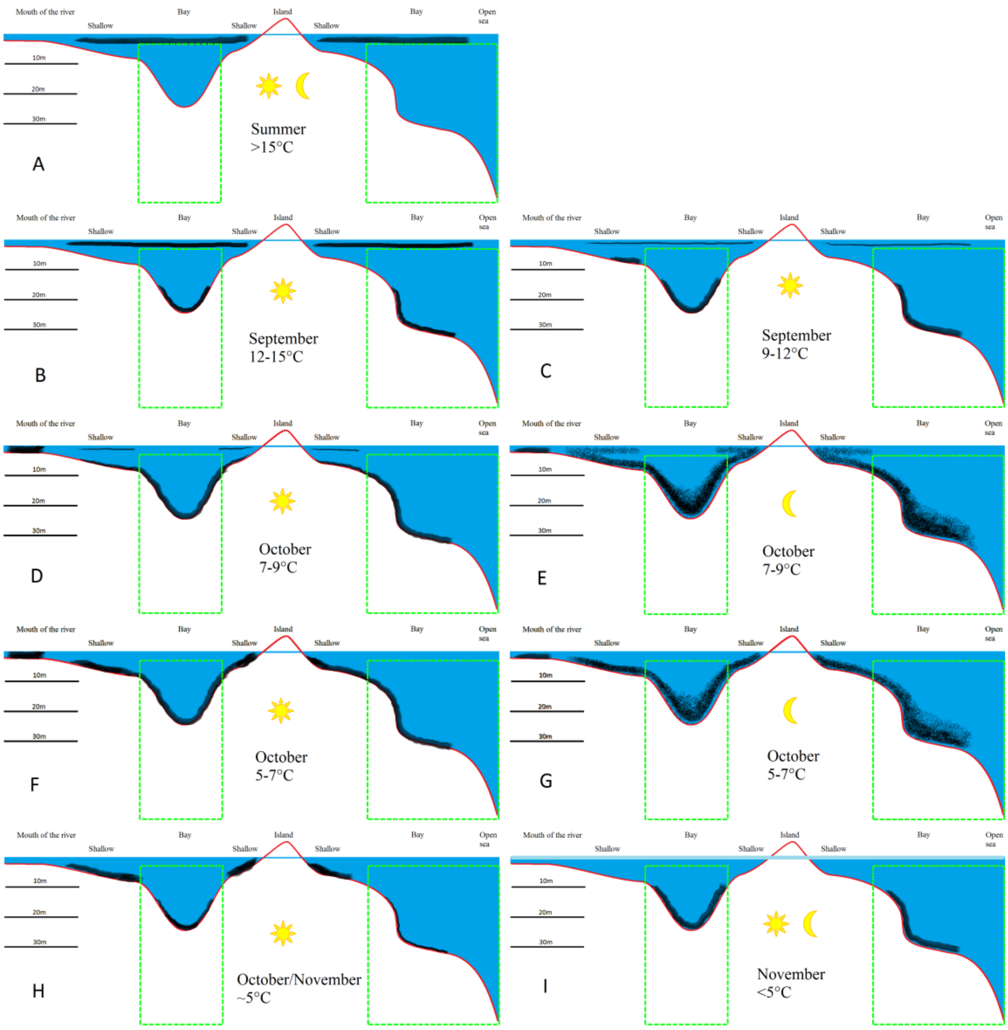


Figure 6A. Temporal and seasonal changes in the horizontal and vertical distribution of vendace in the Norrbotten Archipelago. Red line is the sea bottom contour, blue is water, black color marks the vendace concentrations and green rectangles mark the volume that we are able to sample using echosounder (however, due to the blind zone we are not able to see the fish very close to the bottom). Further explanations to the drawings are given in the text below.

A) Distribution during the warm water season. Vendace is distributed both, day and night close to the water surface and all over the archipelago (including shallow areas).

B) Distribution during the daylight in the autumn when some of the fish (mainly the older age groups) starts migrating to the bottom in the deeper parts of the archipelago.

C) Distribution during the daylight in the autumn when vendace shoals are concentrated mainly in the deeper parts of archipelago. Pre-spawning shoals of river spawning vendace population are concentrated in the mouth of the river areas. Substantial part of vendace younger age groups are still remaining close to the water surface all over the archipelago (including shallow areas).

D) Distribution during the daylight in the autumn when vendace pre-spawning shoals are concentrated mainly in the deeper parts of archipelago. Some part of the pre-spawning vendace has descended also in the shallow coastal areas. Age 0 vendace is essentially remaining close to the water surface mainly in the shallow coastal areas. Spawning in the rivers has started.

E) Distribution during the night time in the autumn when pre-spawning vendace is distributed dispersed close to the bottom mainly in the deeper parts of archipelago. Age 0 vendace is essentially remaining close to the water surface mainly in the shallow coastal areas. Spawning in the rivers has started.

F) Distribution during the daylight in the autumn when pre-spawning shoals are concentrated in the deeper parts of archipelago. Some parts of the coastal spawning population has started spawning in the shallow coastal areas. Age 0 vendace has descended deeper. Spawning in the rivers continues.

G) Distribution during the night time in the autumn when vendace is scattered close to the bottom in the archipelago. Some part of the coastal spawning population has started spawning in the shallow coastal areas. Age 0 vendace has descended deeper. Spawning in the rivers continues.

H) Distribution in the daylight during the spawning period of the coastal spawning population. Spawning aggregations are concentrated in the shallow coastal parts of archipelago and slopes. Shoals of spent fish (river spawners and early coastal spawners) and age 0 vendace are concentrated in the deeper parts of archipelago.

I) Distribution after the spawning time. Vendace winter aggregations are concentrated both, day and night close to the bottom in the deeper parts of archipelago. Formation of the ice cover has started.

Intervjuundersökning av den elektroniska utvecklingen hos siklöjefiskare

Vi har varit i kontakt med några fiskare (de som brukar stå för merparten av fångsterna) och frågat hur den elektroniska utvecklingen har påverkat deras effektivitet i fisket.
Redovisar svaren (som inkluderar trålkompisen också) här:

Ingvar Lerdin: Jag har inte blivit effektivare, de senaste 10 -15 åren har jag inte bytt någon utrustning. Vi kör efter samma spår som på 90-talet. Ska man ha alltför avancerad utrustning och klara av att hantera den på maximalt sätt behöver man goda datakunskaper vilket jag inte har (och förmodligen många andra fiskare heller). Bedriver man siklöjefiske under 5 veckor per år så underhåller man inte kunskapen, dvs jag fiskar inte bättre med avancerad elektronisk utrustning (som jag inte klarar av att använda)

Magnus Persson: Bedömer att han max blivit 4% effektivare pga elektroniken sedan 2000. Han sa att det nästan blev tvärtom i vissa fall. Där han tidigare körde så visade Sonarn alldeles för hård botten och då blev han tvungen att bortse från denna information.

Kjell Strömbäck: Har samma elektronik de senaste 15-20 åren och han bedömer att han inte blivit effektivare.
Han anser att trålarna blivit mindre effektiva sedan man satte in risterna (vilket många anser)

Lennart Sundström: Har samma elektronik som han haft senaste 10 åren. Anser inte att effektiviteten ökat, kör på samma spår som tidigare.

Mats Innala: Har inte någon ny elektronisk utrustning på hela 2000-talet . Har trålat på exakt samma sätt de senaste 15-20 åren.

Daniel Lindblom: har samma elektronik sen minst 10 år och samma plotter sedan minst 20 år. Anser att han inte blivit mer effektiv de senaste 15 åren eftersom han trålar på samma sätt och samma fjärdar.

Janne Holm: Kör i samma spår som han kört upp för 20-25 år sedan. Han anser att han inte blivit effektivare.

Johnny Stålarm: Har samma elektronik sedan när han började tråla i början på 2000-talet. Ingen effektivitetsökning.

Arnold Bodlund: Har blivit max 4 % effektivare tack vare nya kartplotter som inhandlades 10-15 år sedan.

Resten av flottan är de som brukar fiska mindre mängder och brukar inte investera i sitt fiske (varken i båtar eller elektronik).

Slutsatsen av detta: Det har skett mycket lite utveckling på elektronikfronten och de flesta kör i gamla invanda spår.

Rapporterat av Teija Aho & Ingvar Lerdin

WD 5: Stock assessment of vendace (*Coregonus albula*) in the Bothnian Bay (ICES SD 31)

By Massimliano Cardinale and Francesco Masnadi

Assessment method and settings of the base case model configuration

Assessment of vendace in SD 31 was conducted using the Stock Synthesis (SS) model (Methot & Wetzel 2013, Methot et al., 2021). Stock Synthesis is programmed in the ADMB C++ software and searches for the set of parameter values that maximize the goodness-of-fit, then calculates the variance of these parameters using inverse Hessian and MCMC methods. The assessment was conducted using the 3.30.18 version of the Stock Synthesis software under the windows platform.

Uncertainty measures and likelihood

The total likelihood of the model is composed of a number of components, including the fit to the surveys and CPUE indices, tag recovery data (when tagging data are used), fishery and survey length frequency data, age compositions (when present), conditional age at length compositions and catch data. There are also contributions to the total likelihood from the recruitment deviates and priors on the individual model parameters (if any). The model is configured to fit the catch almost exactly so the catch component of the likelihood is generally small (although catch penalties might be created and catches are entered with uncertainty). Details of the formulation of the individual components of the likelihood are provided in Methot & Wetzel (2013).

Samples sizes, CVs, data weighting

For the commercial fleet, the CV of the catches was set to 0.05. The CV of the initial catches of the commercial fleet was set to 0.1 to add extra variability. The annual sample size associated with the length distribution data is reported as number of trips sampled for commercial catches and as number of hauls for the acoustic survey.

The CV of the commercial CPUE index was available and had an average of 0.29 over the entire time series. On the other hand, the CV of the acoustic survey was not considered reliable (in absolute terms) but the interannual differences were assumed to reflect the true changes in the precision of the index between years. Therefore, an average value of 0.29 is assumed for the CV of the acoustic survey, which was then scaled to retain the interannual differences.

The relative weighting of the length compositions of the base case model were estimated internally to the model using Dirichlet multinomial distribution. For the conditional age at length compositions (ALK), the sample size was manually reduced (i.e. a lambda factor of 0.01 was applied to the ALK) to match the sample size of the length compositions. This was done as the sample size of the ALK is expressed in number of aged fish while the sample size of the length compositions is in number of trips (commercial) or hauls (survey) per year. The Hessian matrix computed at the mode of the posterior distribution was used to obtain estimates of the covariance matrix, which was used in combination with the Delta method to compute approximate confidence intervals for parameters of interest.

Assessment model: base case model configuration

The assessment model of vendace in SD 31 is a one area, quarterly, length-based model where the population is comprised of 12+ age-classes (with age 12 representing a plus group) with sexes combined (male and females are modelled together).

The model starts in 1965 and the initial population age structure was assumed to be in an exploited state, so that the initial catches was assumed to be the average of preceding five years (1960-1964) in the time series. Fishing mortality was modelled using a fleet-specific method (Methot et al., 2021). Option 5 was selected for the F report basis; this option corresponds to the fishing mortality requested by the ICES framework (i.e. simple unweighted average of the F of the age classes chosen to represent the F_{bar} (age 1-3)).

Spawning stock biomass and recruitment

Spawning biomass was estimated at the beginning of the year and it was considered proportional to fecundity. In the model, the recruitment was assumed to be only a single event occurring at the beginning of the year. Recruitment was derived from a Beverton and Holt (BH) stock recruitment relationship (SRR) and variation in recruitment was estimated as deviations from the SRR. Recruitment deviates were estimated for 1991 to 2020 (30 annual deviations). Recruitment deviates were assumed to have a standard deviation (σ_R) of 0.7, which was set as the value internally derived by the model. σ_R is the stochastic recruitment process error and the estimation of this parameter within integrated models is generally recognised to be problematic (Kolody et al., 2019) so that σ_R individual recruitment estimates is fixed at a values that is large enough to prevent the SSR from constraining individual recruitment estimates (e.g. analogous to traditional VPA) (Kolody et al., 2019). A meta-analysis of the estimation of σ_R done outside the operative model (ISSF, 2011) yielded a median estimate between 0.2 and 0.5, which suggested that σ_R is often inflated in assessment models. The steepness (*h*) for the SRR was set at 0.8, which is close to the value (0.78) estimated from FishLife for the species (Thorson, 2017; https://github.com/James-Thorson-NOAA/FishLife).

Growth, weights and maturity

Growth parameters were estimated internally by the model except L_{inf} which was set at 18.3 cm. Weight was estimated from a length-weight relationship (a= 4e-06, b= 3.0962) while length at maturity was described by a sigmoidal function with $L_{50\%}$ set at 11.8 cm. L_{inf}, length-weight and length at maturity parameters were fixed and derived externally using survey and commercial data. Details on how weight and length at maturity were derived are included in the stock annex.

Natural mortality (background mortality; M1)

For this benchmark assessment, the natural mortality has to be divided in two fraction cause of the seals predation ($M = M1+M2$). Since the new version of Stock Synthesis assessment model can deal with these two types of source of mortality separately, from now on we will refer to background mortality, or *M1*, as the non-seal mortality. Predation mortality, or *M2*, is estimated by the model using timeseries of vendace composition by seals.

Age-varying M1 for the reference model was set equal to the one of last year assessment (Fig. 1) that was estimated based on the methods described in Then et al. (2015) and Lorenzen (1996).. In order to reduce the number of parameters to be used in the model, natural mortality was set using 5 breaks: age 0.5, 1.5, 5.5, 10.5 and 11.5, where M for the adjacent ages is simply linearly interpolated using the values estimated for the age breaks.

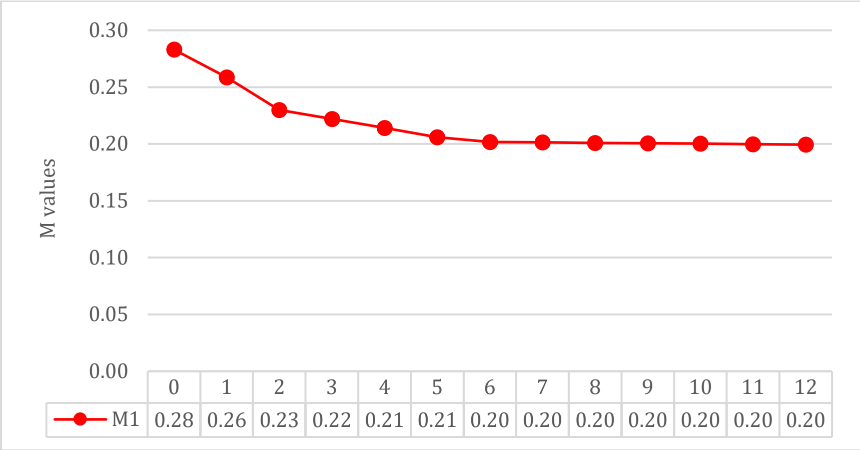


Figure 1. Vendace SD 31. The age-specific natural mortality used in the reference model.

Table 1. Vendace SD 31. Natural mortality (M1) vector by breaks used in the reference model.

Age 0.5	Age 1.5	Age 5.5	Age 10.5	Age 11.5
0.27	0.24	0.20	0.20	0.20

Fishery dynamics

Fishery selectivity of the reference model is assumed to be length-specific and time-invariant. For both commercial fleet and surveys, a double-normal selectivity was used but constrained to mimic a logistic in the right side of the curve. All data inputs are summarized in Table 3 while in Table 4 the configuration of the reference model is reported.

Table 3. Vendace SD 31. Input data used in the Stock Synthesis models.

TYPE	NAME	YEAR RANGE	RANGE
Catches	Catches in tonnes for each year	1965- 2020	
Lenght compositions	Catch in proportions per lenght class	Commercial fleet: 1965-2020 Acoustic survey: 2009-2020 (excluding 2015 and 2016) Commercial CPUE: 1999-2020 Seal stomachs: 2008, 2015, 2019 and 2020	8 – 25 cm

Maturity ogives	Empirical maturity at lenght estimated from commercial and survey data		8 – 25 cm
Natural mortality	Natural mortality by age class costant for the entire time series derived from Then et al., 2015 and Lorenzen 1996		0 - 12+
Surveys indices	Density index from acoustic survey and biomass index from commercial CPUE	Acoustic survey: 2009-2020 Commercial CPUE: 1999-2020	
Seal consumption	Estimates of vendace in tonnes consumed by the seals	1980-2020	
SSB index	SSB proportional to fecundity		

Table 4. Vendace SD 31. Settings of the Stock Synthesis assessment base case model. The table columns show: number of estimated parameters, the initial values (from which the numerical optimization is started), the intervals allowed for the parameters, the priors used (value and standard deviation), the value estimated by the model and its standard deviation. Parameters in bold are set and not estimated by the model.

Parameter	Number estimated	Initial value	Bounds (low,high)	Prior	Value (MLE)	Standard deviation
Natural mortality (M1) (age classes 0.5, 1.5, 5.5, 10.5, 11.5)		**0.27, 0.24, 0.20, 0.20, 0.20**				
Natural mortality (M2) historical (1964-1979)	1	0.21	(0, 4)	No_prior	0.09	0.024
M2 yearly deviations (1980-2020)	41					
Growth (biphasic)						
L_at_Amin	1	10.1	(3, 15)	No_prior	10.16	0.12
L_at_Amax		**18.3**				
VonBert_K_young	1	0.308	(0.05, 0.8)	No_prior	0.37	0.022
Age_K_mult	1	0.74	(0.01, 1)	No_prior	0.28	0.05
CV_young	1	0.06	(0.05, 0.7)	No_prior	0.017	0.007
CV_old	1	0.15	(0.05, 0.7)	No_prior	0.12	0.012
Length-weight						

Wtlen_1		**4e-06**				
Wtlen_2		**3.0962**				
<u>Maturity at length</u>						
Mat50%		**11.8**				
Mat_slope		**-1.2**				
<u>Stock and recruitment</u>						
Ln(R_0)	1	13.15	(9, 20)	No_prior	17.36	0.07
Steepness (h)		**0.80**				
Recruitment variability (σ_R)		**0.70**				
Ln (Recruitment deviation): 1991 - 2020	30					
Recruitment autocorrelation	1	0.3	0, 1	No_prior	0.17	0.18
<u>Initial catches</u>		Average of 1960-1964				
Commercial fleet initial fishing mortality	1	0.4	(1e-05, 4)	No_prior	0.063	0.011
<u>Selectivity (double normal)</u>						
Commercial fleet						
Size_DblN_peak_Fleet	1	14.8	(8, 23)	No_prior	15.49	0.76
Size_DblN_ascend_se_Fleet	1	2.4	(-15, 12)	No_prior	2.73	0.27
Acoustic Survey						
Size_DblN_peak_Acoustic	1	15.6	(8, 23)	No_prior	15.7	1.64
Size_DblN_ascend_se_Acoustic	1	2.7	(-15, 12)	No_prior	3.01	0.56
Seal consumption						
Size_DblN_peak_Seals	1	15.1	(8, 23)	No_prior	15.3	0.52
Size_DblN_ascend_se_Seals	1	1.44	(-15, 12)	No_prior	1.58	0.31
<u>Catchability</u>						
Acoustic survey (floating option)						
Ln(Q) – catchability		**-3.78**				
Trapnet survey						

Ln(Q) – catchability		**-7.91**				
Dirichlet parameters						
ln(DM_theta)_Fleet	1	4.57	(-5, 5)	Normal (0, 1.813)	4.75	0.75
ln(DM_theta)_Seals	1	3.95	(-5, 5)	Normal (0, 1.813)	4.27	0.93
ln(DM_theta)_Acoustic	1	4.20	(-5, 5)	Normal (0, 1.813)	4.61	0.84

All parameter estimates and variances were reasonably well estimated (i.e., CV < 1) with a minor exception for recruitment autocorrelation which had a CV very close to 1. A normal prior of 0 (SD = 1.813) was used on the Dirichlet parameters, which is recommended to counteract the effect of the logistic transformation between the Dirichlet parameter and the data weighting (Methot et al. 2021).

Exploratory runs

All exploratory runs were based on the reference model with middle level of seals, steepness equal to 0.8 and low M1. The following alternative configurations were explored during the benchmark session:

Name	Brief description	Reason
Half_indexCV	Used half of CV in CPUE and Survey data	To test the effect of tuning index accuracy on the result
ALK_weight	Dirichlet parameters used	To test the effect of different weighting procedure for the ALK component
TimeVar_Lmin	time varing Lmin (from 1997)	To test if there was an improvement in the LFD fitting
CS_sel	Cubic Spline selectivity for commercial fleet	To test if there was an improvement in the LFD fitting
M1_est	M1 estimated inside the model	To test other possible value of M1
AgePlus8	Age plus group set to 8+	To test the effect of a smaller Age plus group
Acoustic	Reference run without the CPUE time series	To test the effect of removing source of information (tuning index)
CPUE	Reference run without the Acoustic data (time series LFDs and ALKs)	To test the effect of removing source of information (fishery independent data)

In *Half_indexCV* run, reducing the CV led to no substantial improvements in indices and LFDs fitting. *ALK_weight* and *TimeVar_Lmin* configurations were the ones that diffed most from the

reference run in final model results (bigger relative change in Fig X6) but were discarded by the group because of the overall worse diagnostic (table XXY). *CS_sel* run shows a slightly better diagnostic than the ref run (final *W*: 0.94) but looking at the sensitivity plot no important improvement was noted by the group such as to prefer this setting to the reference one (smaller relative change in Fig X6 and small impact on the final result in Fig X7). The alternative run *M1_est* reveals implausible result in terms of *SBB* and *F* and final *M* (*M1*+*M2*) revealing the inability to estimate *M1* within the model. Similar to *CS_sel,* changing in the plus group also does not improve the model fitting and has a small impact on the final result (Fig X6 and X7).
The last two alternative runs tested reveals a quite stability of the model also without important source of information (tuning indices or fishery independent LFDs). Considering the universally recognized value of tuning data (survey data above all; Gunderson 1993), this result turned out to be unexpected. Nevertheless, some explanations can be formulated:

- the model is mostly driven by catch data;

- the survey data are collected in the same moment of commercial one (autumns) so no much extra information on population structure are added from survey LFDs (as commonly happens in other cases for example improving juveniles length frequency).

Table XXY - Summary table of alternative runs diagnostics. *Reference* refers to run 13 of the ensemble grid.

				Goodness of the fit							Consistency				Prediction skills							
				Run test					Joint-residuals		Retrospective analysis				Hindcasting (MASE)							
Run	Convergence	Total_LL	N_Params	CPUE	Survey	Len_Fleet	Len_Seals	Len_Survey	Index	Length	Retro_SSB	Forecast_SSB	Retro_F	Forecast_F	CPUE	Survey	Comb	Len_Fleet	Len_Seals	Len_Survey	Len_Comb	*W(Diagnostics)*
Reference	0.000475462	450.763	217	Passed	Passed	Passed	Failed	Passed	36.9	3	0.16	0.18	-0.15	-0.12	0.81	0.69	0.77	0.43	0.41	0.32	0.42	0.89
Half_indexCV	0.0852805	476.273	217	Passed	Passed	Passed	Failed	Passed	31.5	3.1	0.20	0.27	-0.18	-0.18	1.02	0.73	0.93	0.44	0.48	0.45	0.45	0.83
ALK_weight	0.0369596	4380.63	219	Failed	Passed	Passed	Passed	Failed	54.2	5.8	-0.05	0.22	0.05	0.18	2.31	3.10	2.57	0.49	0.97	0.58	0.63	0.67
TimeVar_Lmin	0.0770515	442.569	241	Failed	Passed	Passed	Passed	Passed	42.1	2.6	0.37	0.41	-0.23	-0.21	1.18	0.83	1.07	0.40	0.34	0.50	0.38	0.61
CS_sel	1.23648	447.121	220	Passed	Passed	Passed	Passed	Passed	36.6	2.9	0.12	0.15	-0.18	-0.15	0.90	0.70	0.83	0.45	0.32	0.31	0.41	0.94
M1_est	Implausible model result																					
AgePlus8	0.246619	447.899	217	Passed	Passed	Passed	Failed	Passed	36.8	3.00	0.17	0.19	-0.15	-0.12	0.81	0.73	0.79	0.43	0.38	0.39	0.41	0.89
Acoustic	0.00714788	467.316	217	NA	Passed	Passed	Failed	Passed	50.1	3.00	0.07	0.04	-0.08	0.00	NA	0.99	NA	0.36	0.37	0.48	0.36	0.86
CPUE	0.00266939	247.585	217	Passed	NA	Passed	Passed	NA	25.90	2.50	0.02	-0.01	-0.01	0.05	0.68	NA	NA	0.44	0.38	NA	0.42	1.00

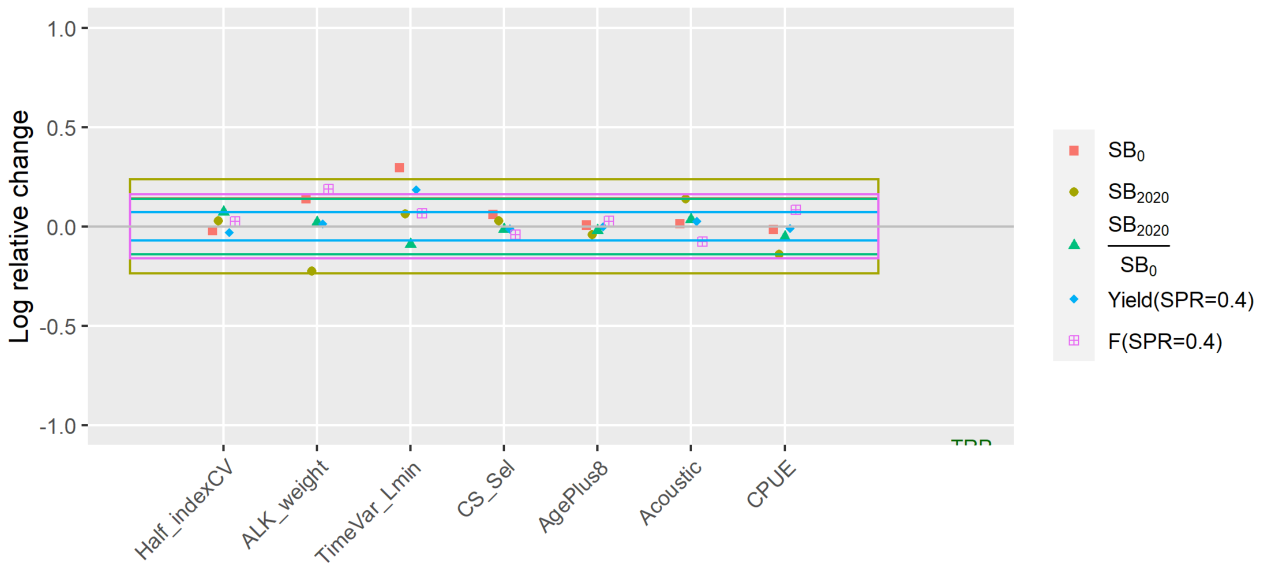


Figure X1 - Vendace SD 31. Sensitivity plot of alternative runs tested. The Log relative change refers to changes between each alternative and the reference one (run 13 of the ensemble grid): 0 means no change. Changes are calculated on a set of predefined yield, biomass and F model outputs.

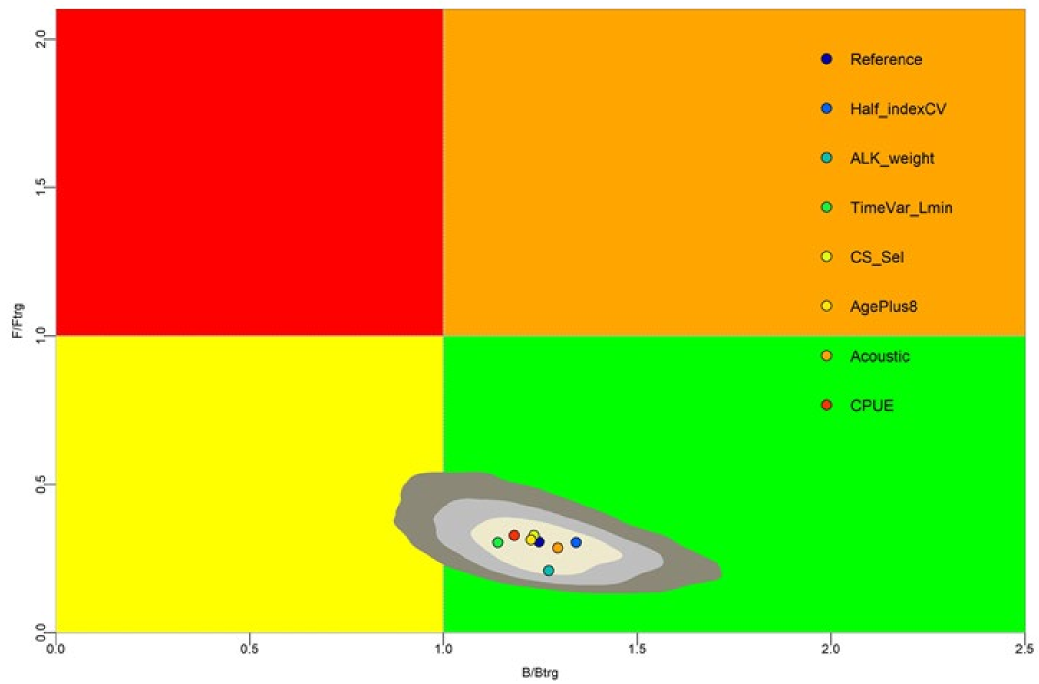


Figure X2 - Vendace SD 31. Kobe plots showing the relative stock size (SSB/SSBtarget) over relative exploitation (F/Ftarget) of all different alternative runs tested. “Reference” refers to run 13 of the ensemble grid.

Base model run and diagnostics

Overview of the datasets included in the base case Stock Synthesis model is shown in Figure 3. The diagnostic figures included in the following chapters are related to the reference model developed before the benchmark. Those were used to compare between model configurations and are considered valid for this purpose. The final model as agreed at the benchmark with its retrospective diagnostic is presented in the next sections.

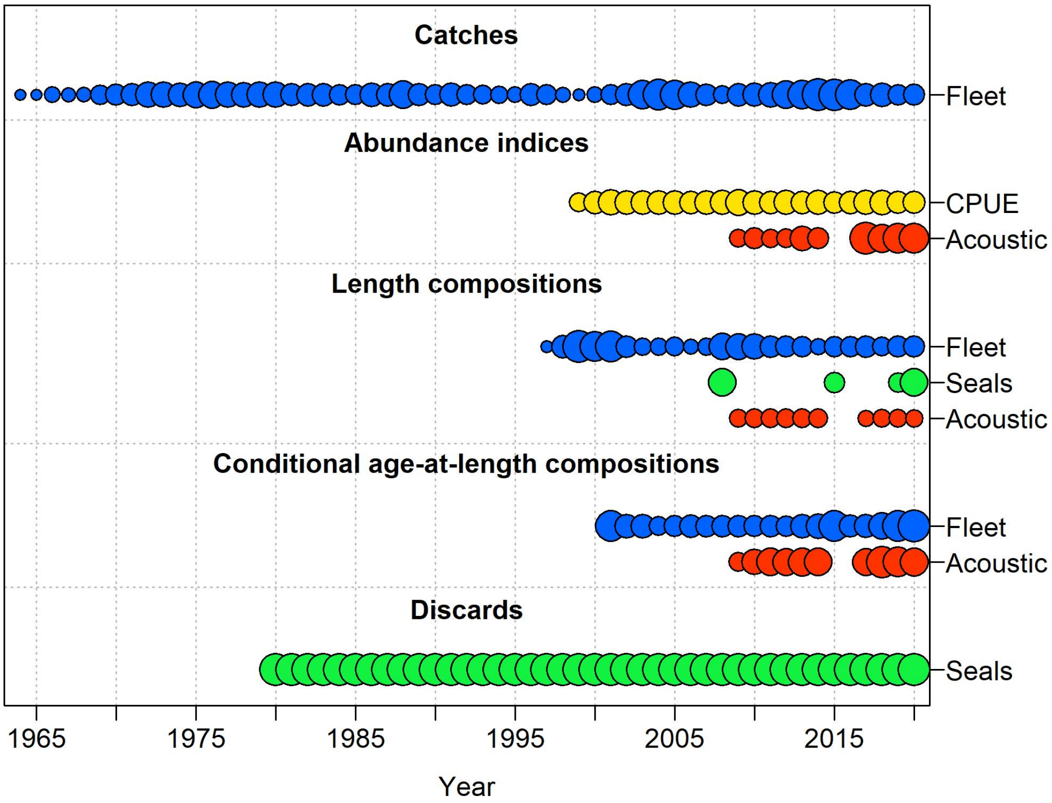


Figure 3. Vendace SD 31. Summary of the input time series included in the model.

The selectivity of all fleets is well estimated (Figure 4).

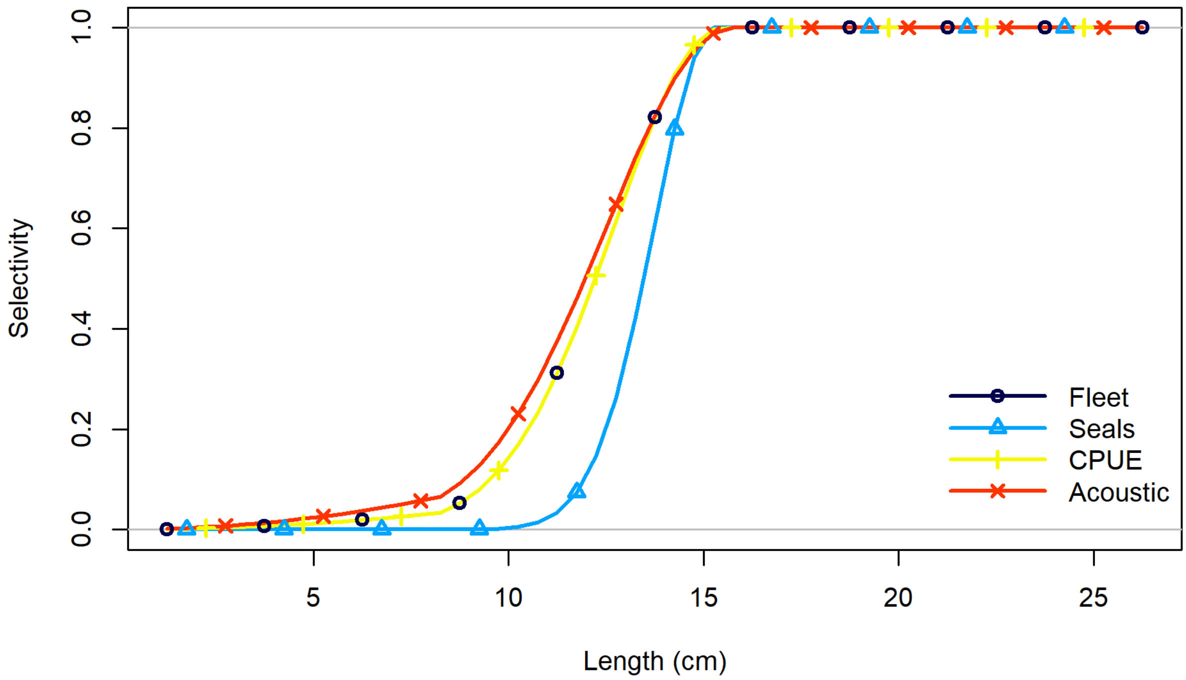


Figure 4. Vendace SD 31. Length based selectivity by fleet.

The fitting of the model was satisfactory, with the aggregated length compositions well reconstructed. The residuals are quite low, generally above -2.0 and below 2.0, and without particular patterns (Figure 5 and 6).

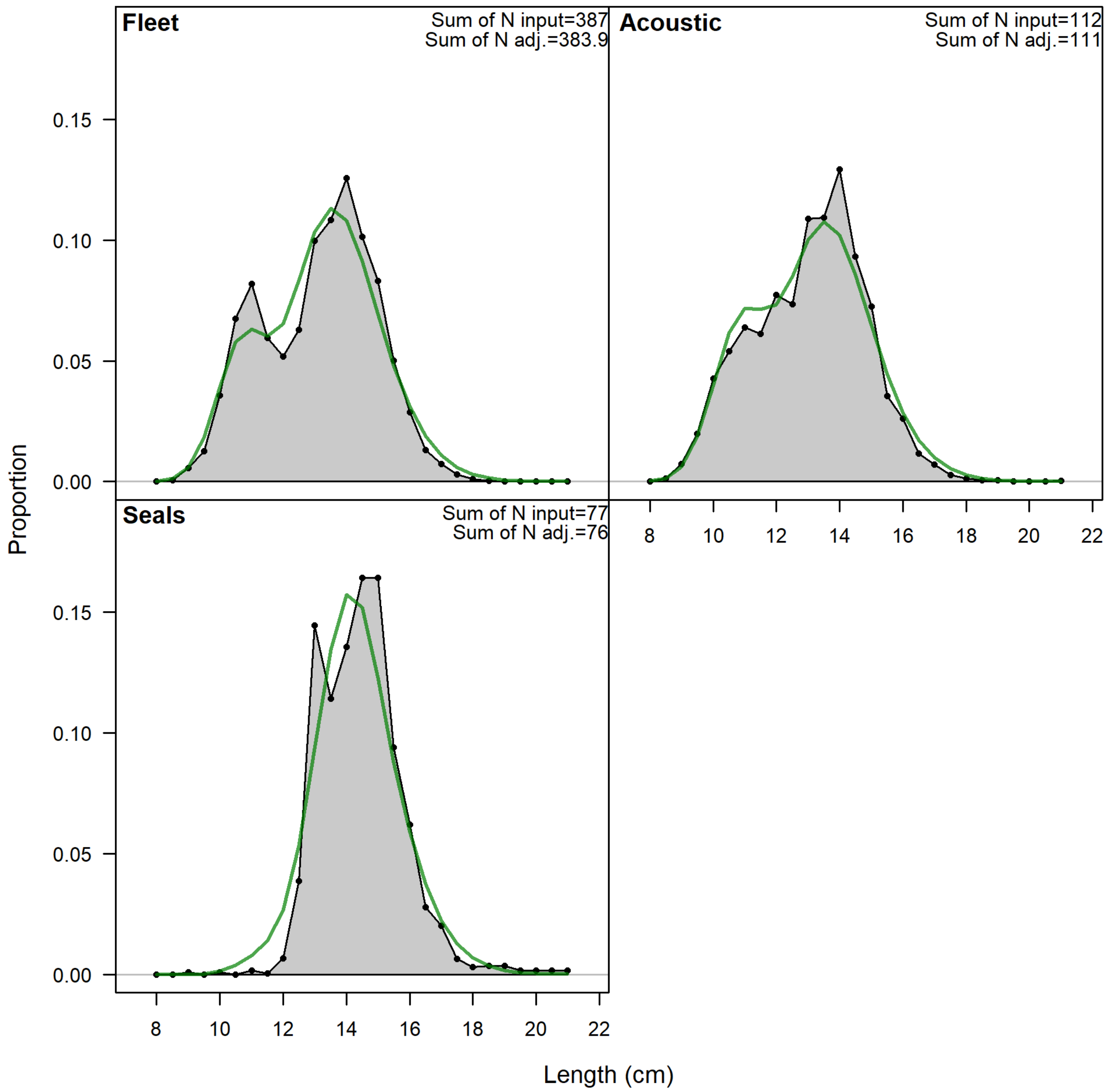


Figure 5. Vendace SD 31. Model fits to length composition data.

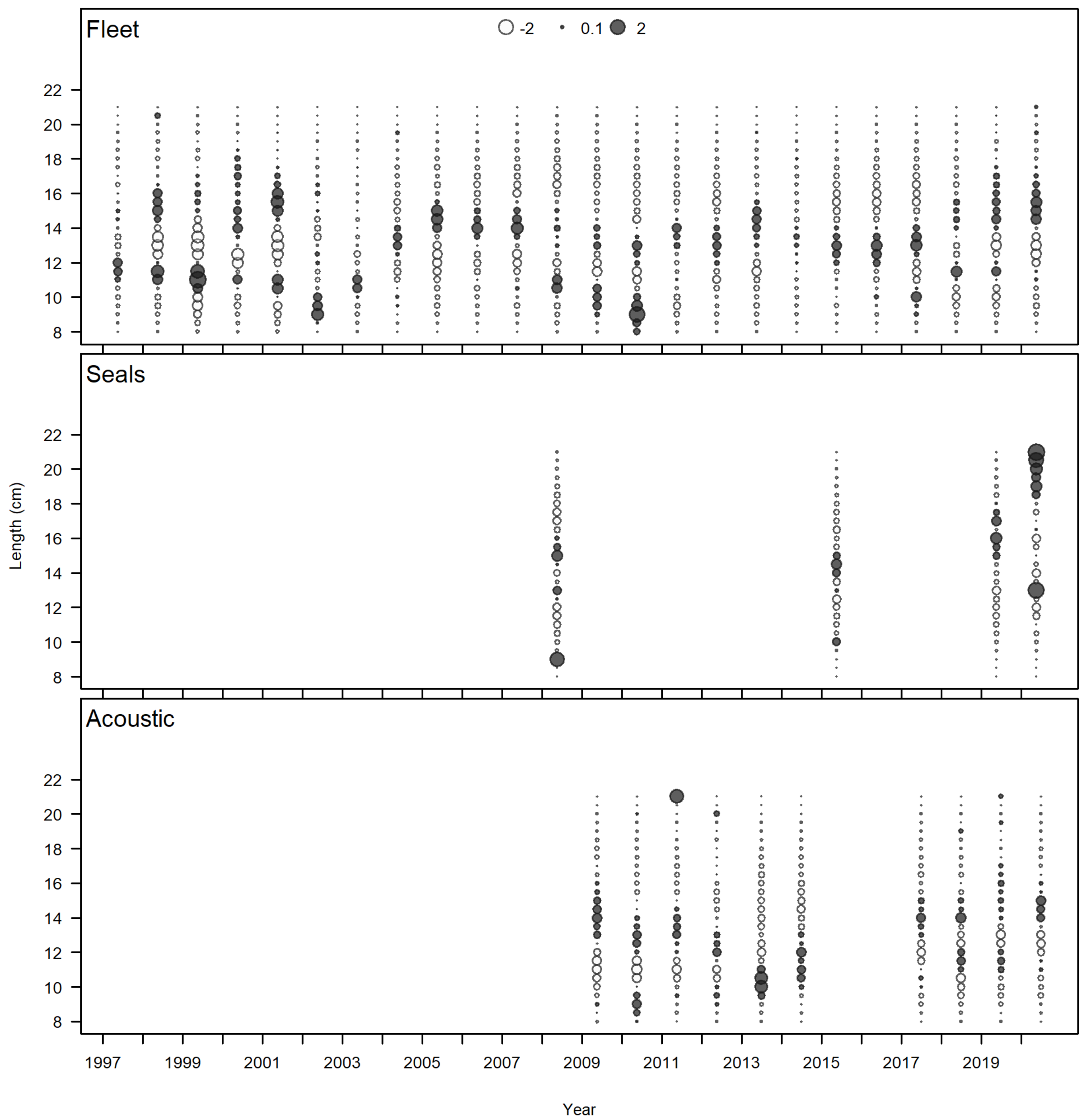


Figure 6. Vendace SD 31. Residuals of fits to length composition data for the different fleets.

Overall, the model does provide a very good fit to the commercial CPUE and moderate fit of the acoustic survey (Figures 7 and 8).

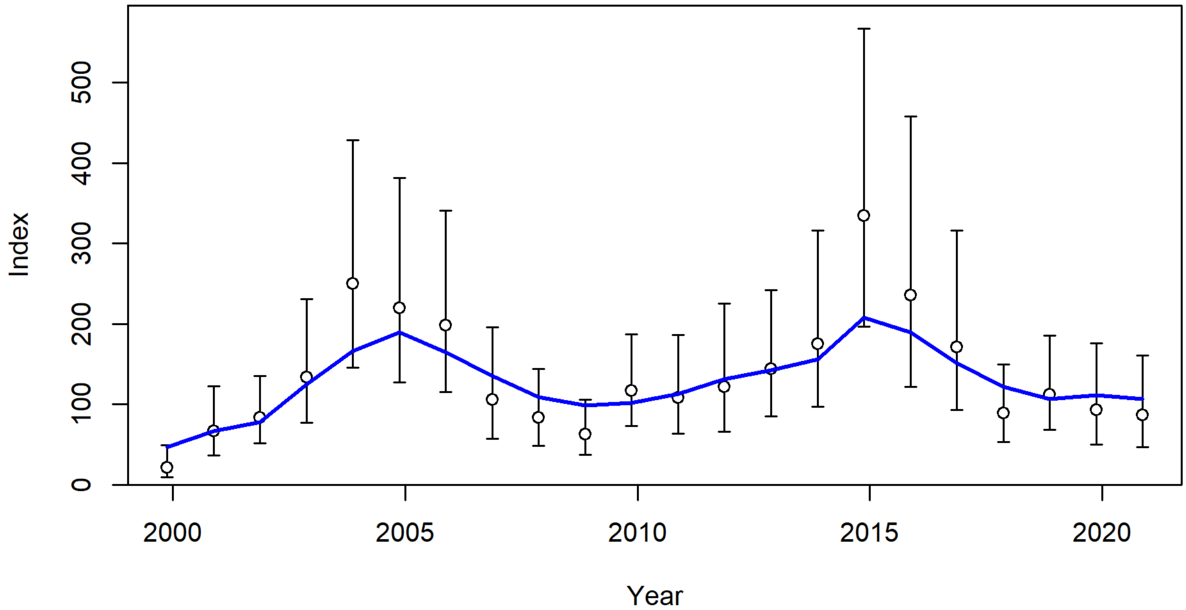


Figure 7. Vendace SD 31. Model fits to the commercial CPUE index.

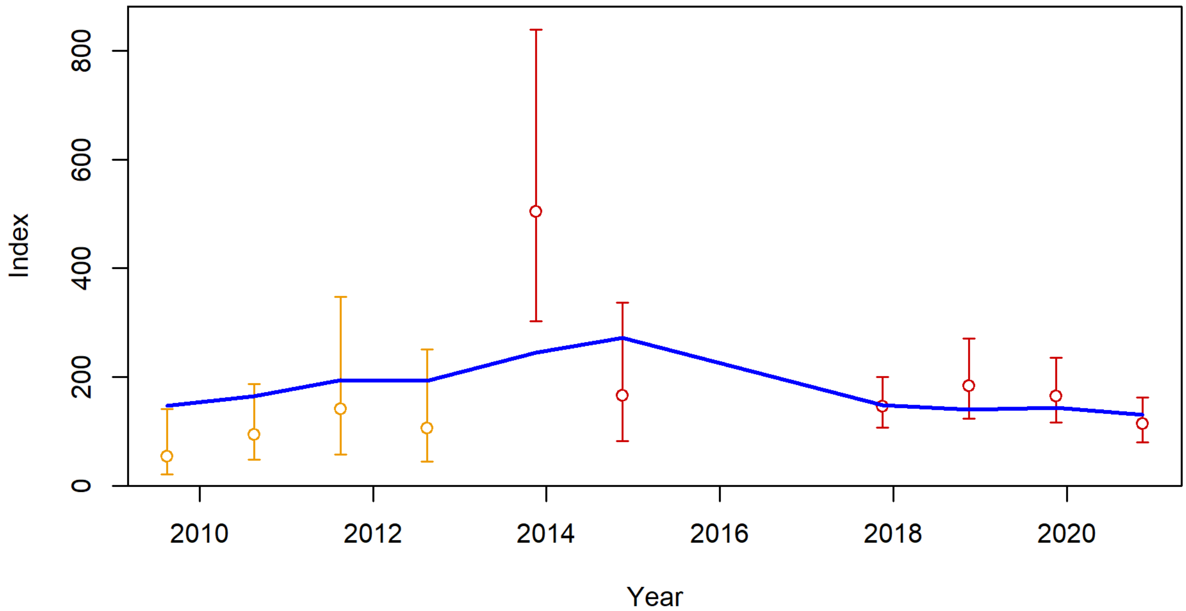


Figure 8. Vendace SD 31. Model fits to the acoustic survey index.

A non-random pattern of residuals may indicate that some heteroscedasticity is present, or there is some leftover serial correlation (serial correlation in sampling/observation error or model misspecification). Several well-known nonparametric tests for randomness in a time-series include: the runs test, the sign test, the runs up and down test, the Mann-Kendall test, and Bartel's rank test (Gibbons and Chakraborti, 1992). Here we used the runs test to evaluate whether residuals of the commercial CPUE index and acoustic survey, and of the length frequency distributions were normally distributed or/and had time trends because this test has been used recently to diagnose fits to indices and other data components in other assessment models (e.g.FAO-GFCM, 2021, Winker et al., 2018, Carvalho et al., 2021). The results of the runs test are presented in Figures 9 and 10. The RMSE runs test indicated that the fit of the length compositions was good because no residuals were larger than 1 and the RMSE was much less than 30%, indicating a random pattern of the length frequency distributions. The RMSE of the indices instead showed a moderate conflict between the commercial CPUE index and acoustic survey with RMSE larger than 30%. The RMSE plot is considered as a tool for identifying trends in residuals and if the standard deviation is tight on a given year this means the fleets are in agreement, even if not fitting well, which is a useful diagnostic. Its purpose is to visualize multiple residuals at once, pick up on periods of substantial data conflicts (width of boxes) and systematic departures in median residuals (loess). The ordinary runs test was passed for all components tested except for seal size compositions. However, when the test is based on a limited number of observations as in this case (i.e. 4), even a time series that well conforms to assumptions of normality and lack of time trend in the residuals will rarely pass a runs test because of the low sample size.

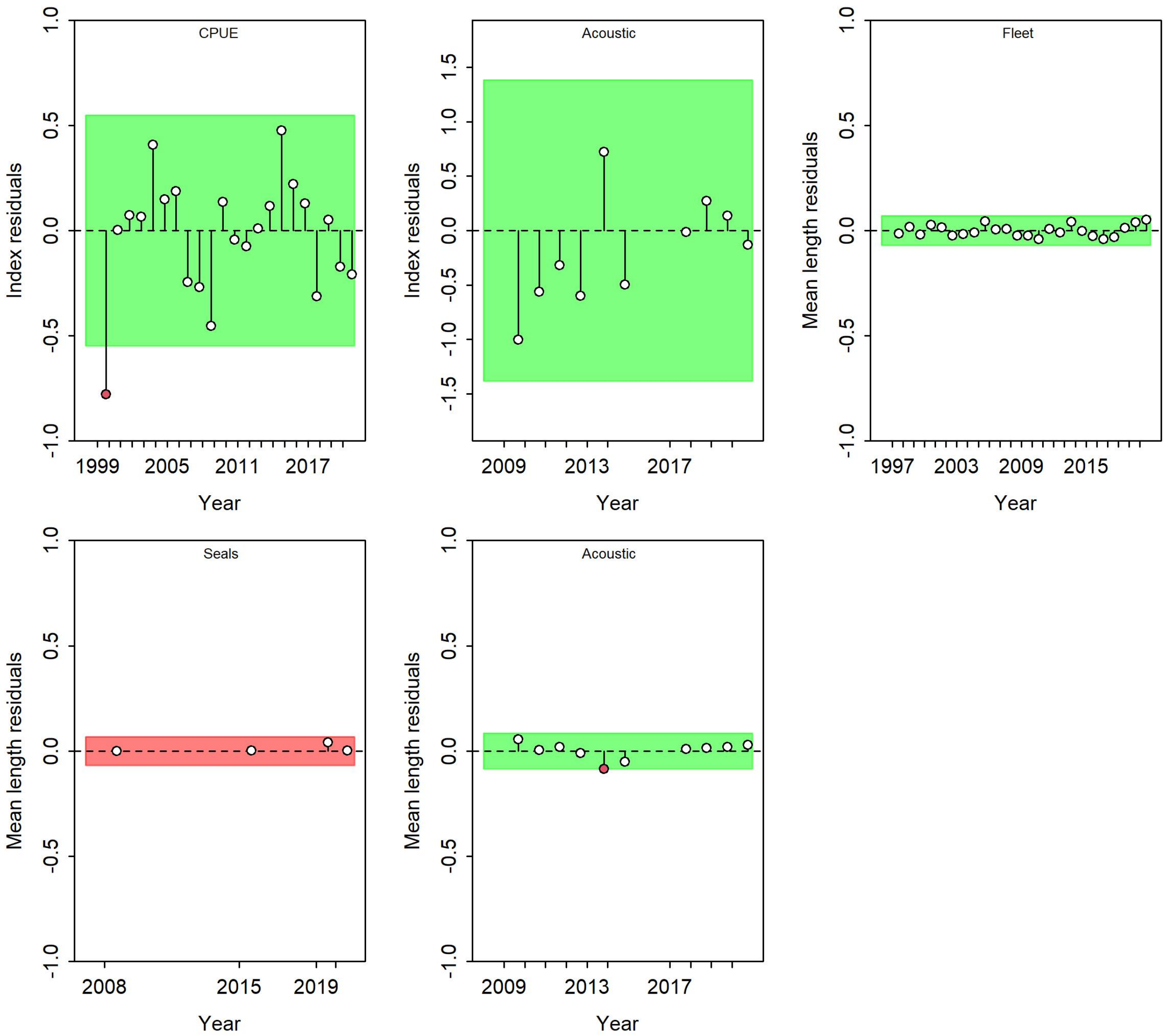


Figure 9. Vendace SD 31. Residuals from runs test analyses for the fit to the commercial CPUE and acoustic survey indices and length distributions of acoustic survey and seal consumption.

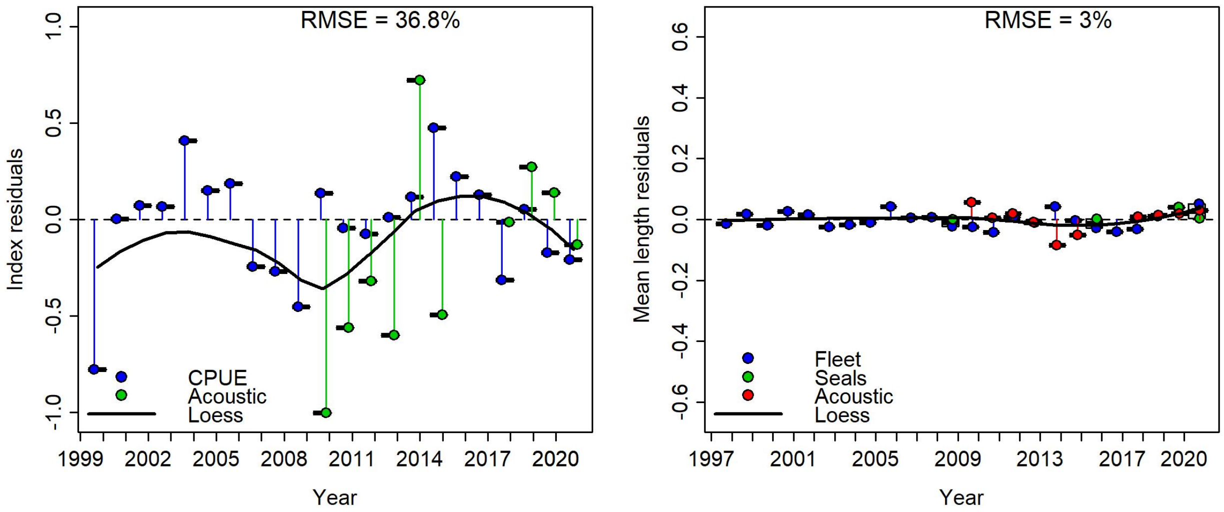


Figure 10. Vendace SD 31. Residuals from the RMSE runs test analyses for the length distributions and the fit to the commercial CPUE and acoustic survey indices.

Jittering

The jitter procedure allows to verify the stability of the model examining the effect of varying the starting values of the model input estimated parameters on the model results. An accurate model should converge on a global solution (i.e. not being stuck in local minima of likelihood surface) across a reasonable range of starting values input parameters. In this case, 200 runs were performed considering a 10% of jitter of the initial parameters, which means that a small random jitter is added to the initial parameter values. Starting values are jittered based on a normal distribution based on the pr(PMIN) = 0.1% and the pr(PMAX) = 99.9%.

The 200 iterations of the jitter test for global convergence resulted in the same results as the reference run (Figure 11), so no local minima are observed as no runs have a likelihood lower than the reference run. It is however important to stress that the absence of a local minima when running jittering is not a guarantee that the model is not indeed stuck in a local minimum, although its absence reduced the risks that this occurs (Subbey 2018).

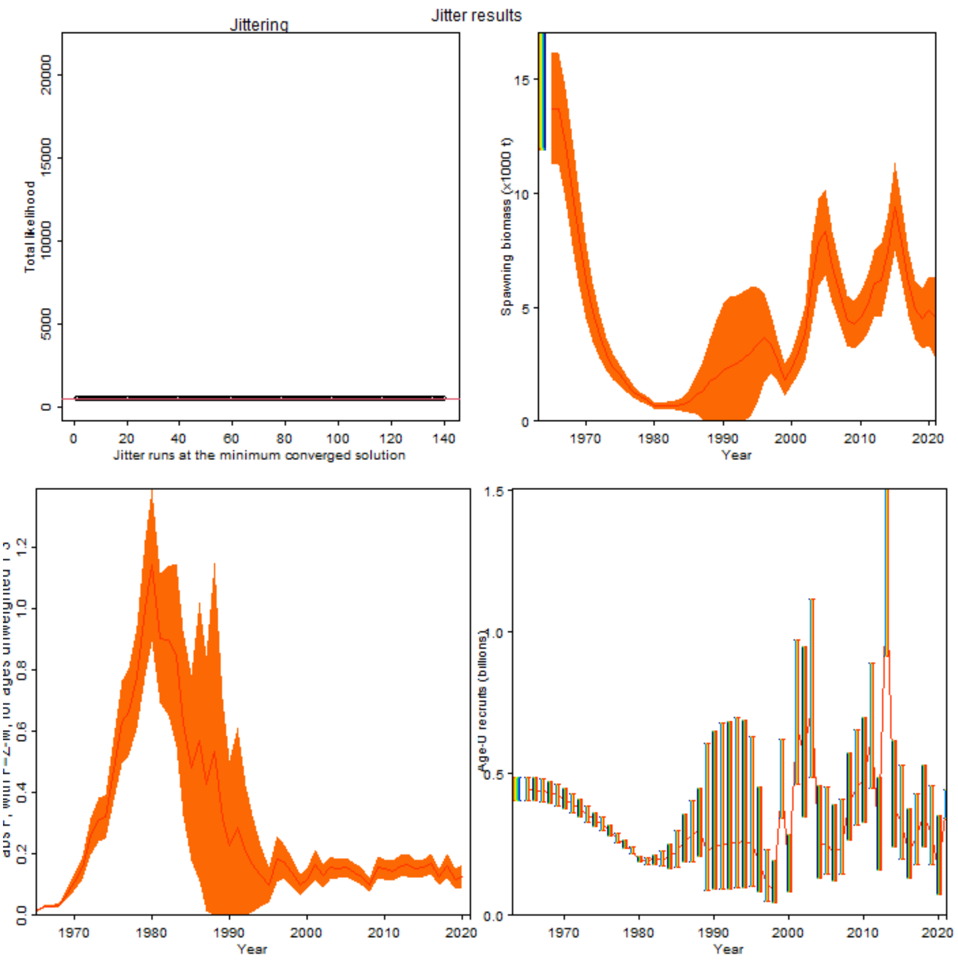


Figure 11. Vendace SD 31. Results from jitter using 200 iterations and an average jitter of 10%.

Retrospective analyses

Retrospective analysis is a diagnostic approach to evaluate the reliability of parameter and reference point estimates and to reveal systematic bias in the model estimation. It involves fitting a stock assessment model to the full dataset. The same model is then fitted to truncated datasets where the data for the most recent years are sequentially removed. The retrospective analysis was conducted to the reference model for the last 5 years of the assessment time horizon to evaluate whether there were any strong changes in model results. Given that the variability of Mohn's rho index depends on life history, and that the statistic appears insensitive to F, Hurtado-Ferro et al. (2014) proposed the following rule of thumb when determining whether a retrospective pattern should be addressed explicitly. Values of Mohn's rho index higher than 0.20 or lower than -0.15 for long-lived species (upper and lower bounds of the 90% simulation intervals for the flatfish base case), or higher than 0.30 or lower than -0.22 for short-lived species (upper and lower bounds of the 90% simulation intervals for the sardine base case) should be cause for concern and taken as indicators of retrospective patterns. However, Mohn's rho index values smaller than those proposed should not be taken as confirmation that a given assessment does not present a retrospective pattern, and the choice of 90% means that a "false positive" will arise 10% of the time. In both cases, model misspecification would be correctly detected more than half the time. The retrospectives of the reference model were rather stable (Figure 12). The estimated Hurtado-Ferro et al. (2014) variant of the Mohn´s rho indices were inside the bounds of recommended values for short-lived species as vendace for both SSB (0.18) and F (-0.16).

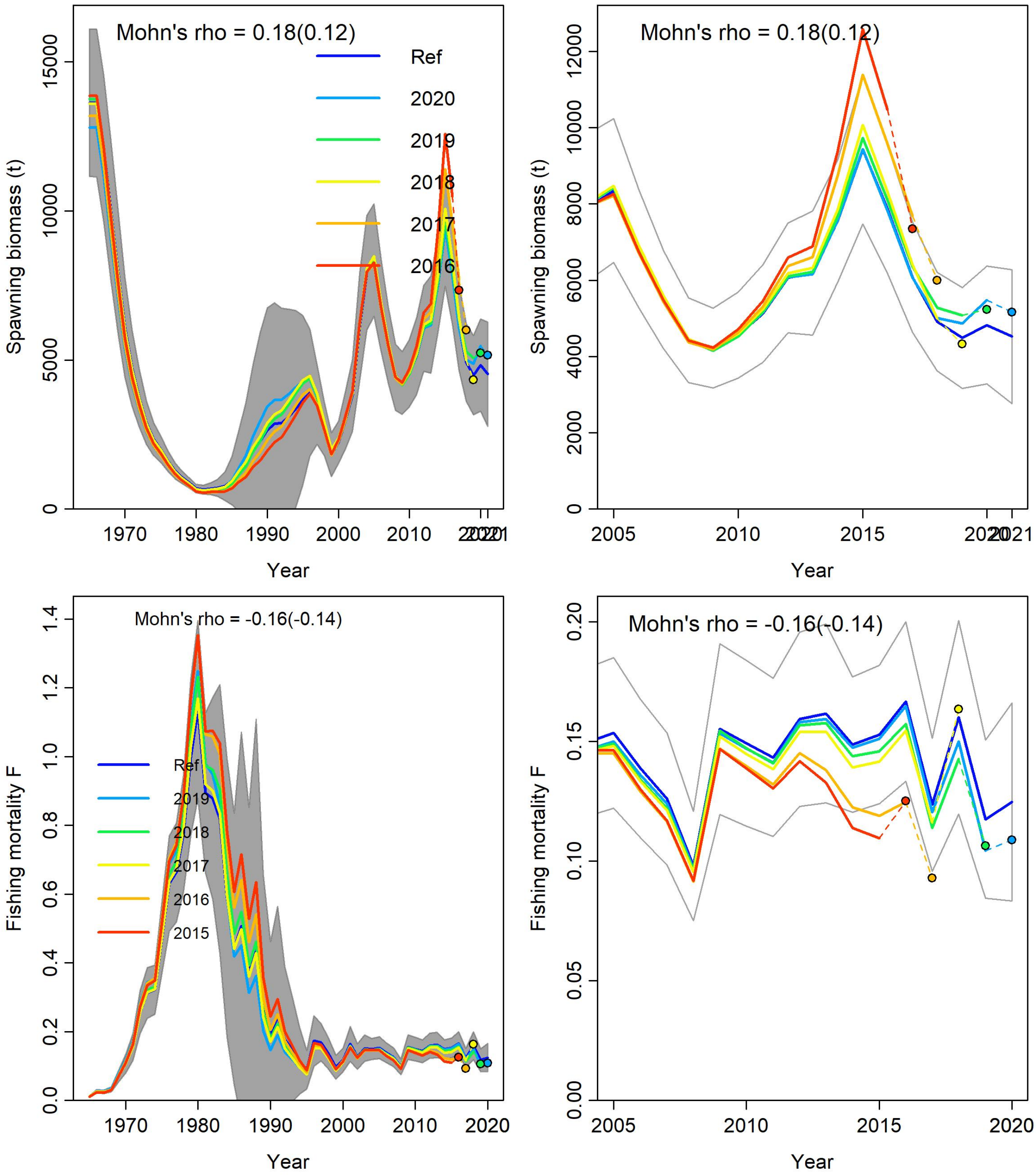


Figure 12. Vendace SD 31. Retrospective analyses of the base case model.

Retrospective analyses of year class strength for young fish shown the estimates of recent recruitment to be unreliable prior to at least between age 1 and 2 (Figure 13), which implies that the strength of an incoming year class is determined with precision only when at least two observations of that year class are included in the model.

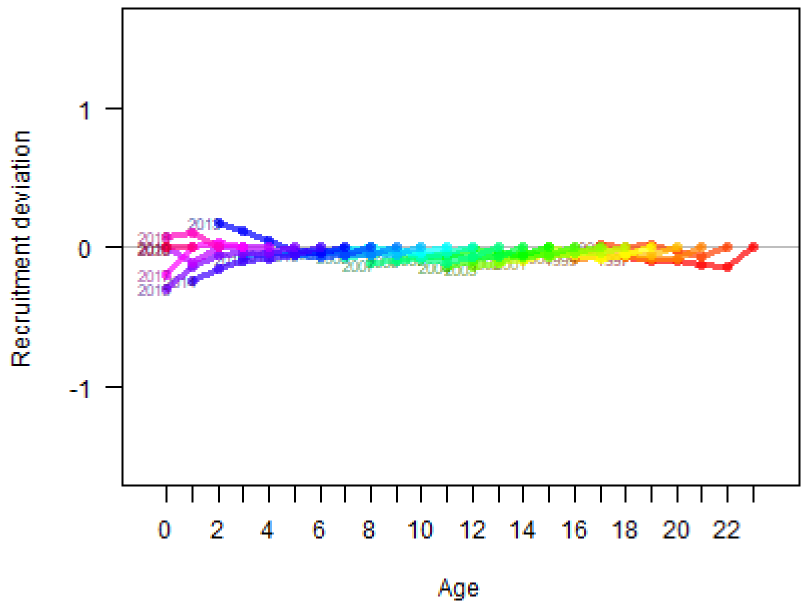


Figure 13. Vendace SD 31. Retrospective recruitment estimates scaled relative to the most recent estimate of the strength of each cohort.

Hindcasting

The provision of fisheries management advice requires the assessment of stock status relative to reference points, the prediction of the response of a stock to management, and checking that predictions are consistent with reality. A major uncertainty in stock assessment models is the difference between model estimates and reality. To evaluate uncertainty often a number of scenarios are considered corresponding to alternative model structures and dataset choices (Hilborn, 2016). It is difficult, however, to empirically validate model prediction, as fish stocks can rarely be observed and counted. Various criteria are available for estimating prediction skill (see Hyndman and Koehler, 2006). One commonly used measure is root-mean-square error (RMSE). RMSE, however, is an inappropriate and misinterpreted measure of average error (Willmott and Matsuura, 2005). On the other hand, mean absolute error (MAE) is a more natural measure of average error, and unlike RMSE is unambiguous. Scaling the average errors using the Mean Absolute Scaled Error (MASE) allows forecast accuracy to be compared across series on different scales. MASE values greater than one indicates that in-sample one-step forecasts from the naïve method perform better than the forecast values under consideration. MASE also penalizes positive and negative errors and errors in large forecasts and small forecasts equally.

Kell et al. (2016, 2021) and Carvalho et al., 2021 showed how hindcasting can be used to evaluate model prediction skill of the CPUE. When conducting hindcasting, a model is fitted to the first part of a time series and then projected over the period omitted in the original fit. Prediction skill can then be evaluated by comparing the predictions from the projection with the observations using for example the MASE indicator (Hyndman and Athanasopoulos, 2013).

Hindcasting was conducted for the base case model (Fig. 17). The results showed that the acoustic survey performs well in hindcasting given that the MASE value is lower than the 1.0 threshold when predicting the index one year ahead.

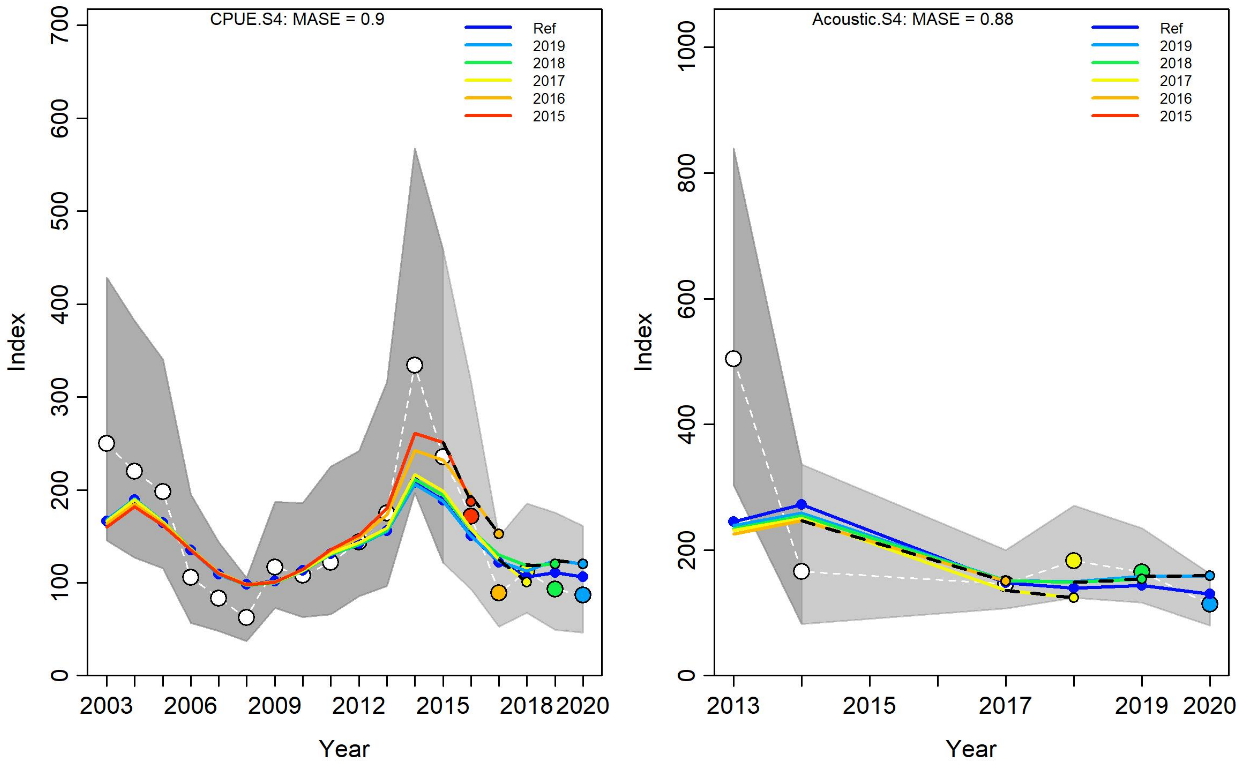
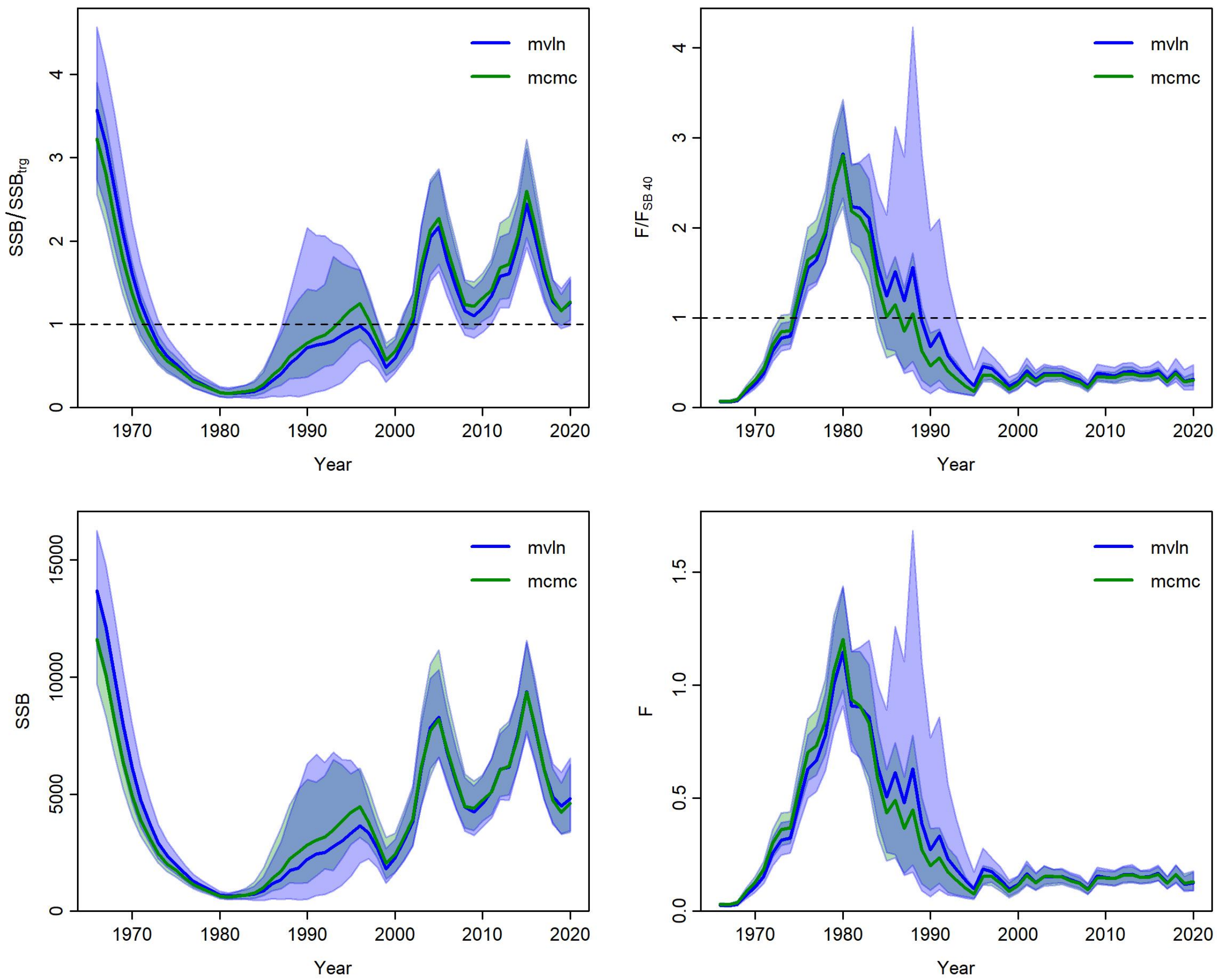


Figure 17. Vendace SD 31. Hindcasting results for the commercial CPUE and acoustic survey showing observed (large white points connected with dashed line), fitted (solid lines) and one year-ahead forecast values (small terminal points). HCxval was performed using one reference model (Ref equal to last year data 2020) and 5 hindcast runs (solid coloured lines) relative to the expected index. The observations used for cross-validation are highlighted as color-coded solid circles with associated 95 % confidence intervals (light-gray shading). The mean absolute scaled error (MASE) score associated with the survey index is denoted in each upper part of the panel

MCMC

Markov chain Monte Carlo (MCMC) methods comprise a class of algorithms for sampling from a probability distribution. It is used in integrated models for detecting misspecification in key fixed parameters or issues with estimation of the parameters. By constructing a Markov chain it is possible to obtain a sample of the desired distribution by observing the chain after a number of steps. The more steps there are, the more closely the distribution of the sample matches the actual desired distribution. MCMC methods create samples from a possibly multi-dimensional continuous random variable, with probability density proportional to a known function. These samples can be used to evaluate an integral over that variable, as its expected value or variance. Practically, an ensemble of chains is generally developed, starting from a set of points arbitrarily chosen and sufficiently distant from each other. Those are then used to estimate the posterior distribution of the parameters of interest within the model.

For Vendace in SD 31, we performed an MCMC run as diagnostic (i.e. thus not for inference, for which a much larger number of iterations would be necessary) using the NUTS algorithm with 3 chains of 50000 iterations each, with 50% of the iterations as burn-in period and no thinning. The results showed that the MCMC is almost identical to the MLE estimated, which is an indication of the robustness of the model (Figure 18).



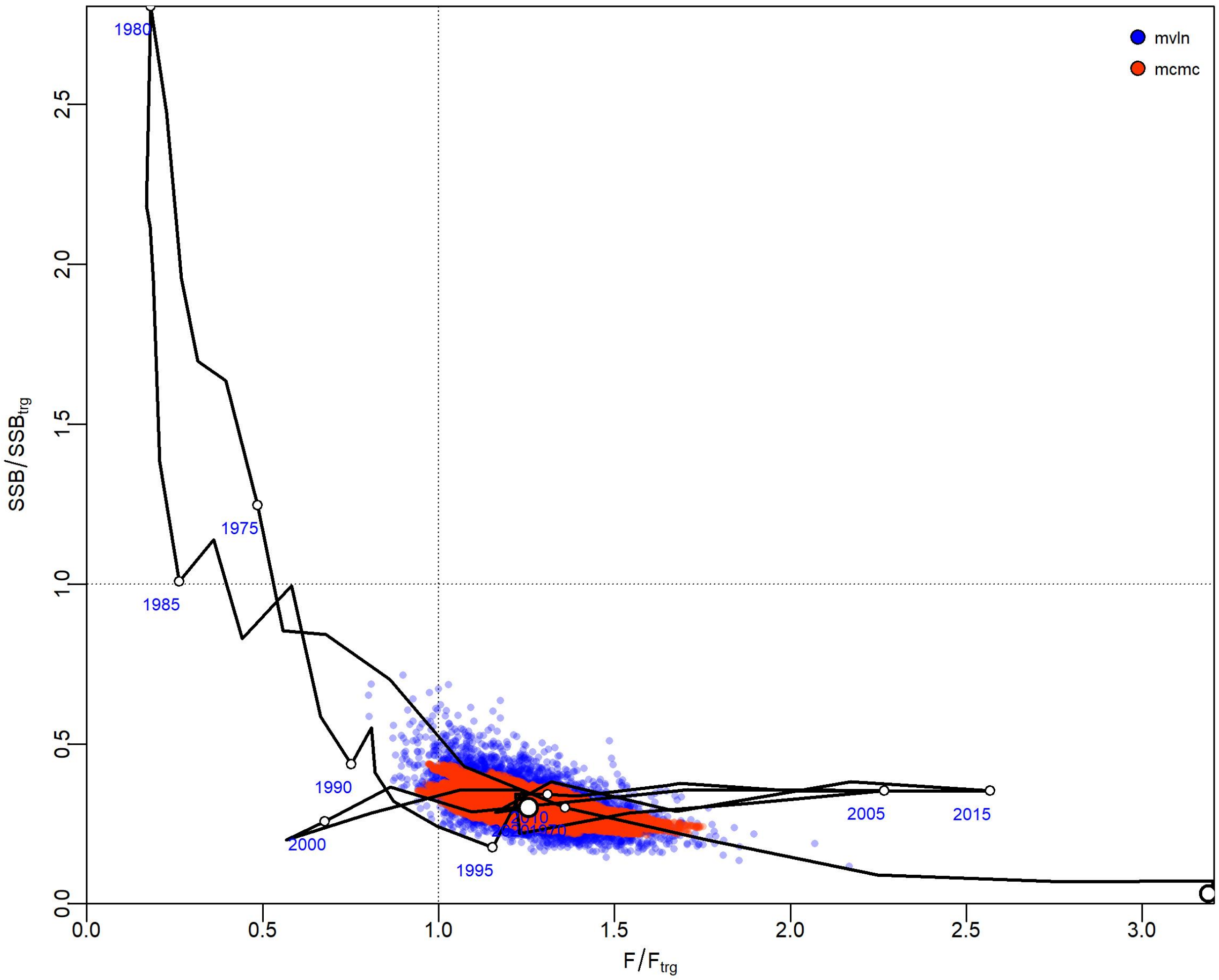


Figure 18. Vendace SD 31. Results of the MCMC analysis in terms of SSB, R and F compared to the MLE model and kobe plot of the 2020 estimations with uncertainty of the MCMC and MLE models.

NUTS algorithm in MCMC (Monnahan et al., 2019) was also used to regularize the model, i.e. to check that all parameters are identifiable. MCMC run with NUTS algorithm confirmed that all parameters of the model are identifiable.

Figure 19. Vendace SD 31. Comparison between MLE (blue points) against posteriors of the reference model obtained by an MCMC (red points) with 50000 iterations, 3 chains, run with NUTS algorithm, with 25000 iterations as burn in and no thinning. The stock trajectory (median) is also showed.

Analysis of surplus production trend

Estimates of Surplus Production (Walters, et al., 2008) can provide a check of whether predictions of changes in biomass can be made reliably based on catch and current biomass (clockwise or linear behaviour) or whether there has been non-stationarity in production processes, i.e. are dynamics driven by climate and oceanic conditions (counter clockwise). This is important for example for the development of MPs in the MSE process. In the case of Vendace in SD 31, the figure shows in general a clockwise pattern so that the stock is in general changes in biomass can be made reliably based on catch and current biomass (Figure 23) although recent years have shown the tendency of the stock to produce larger year classes than predicted by the stock-recruitment function .

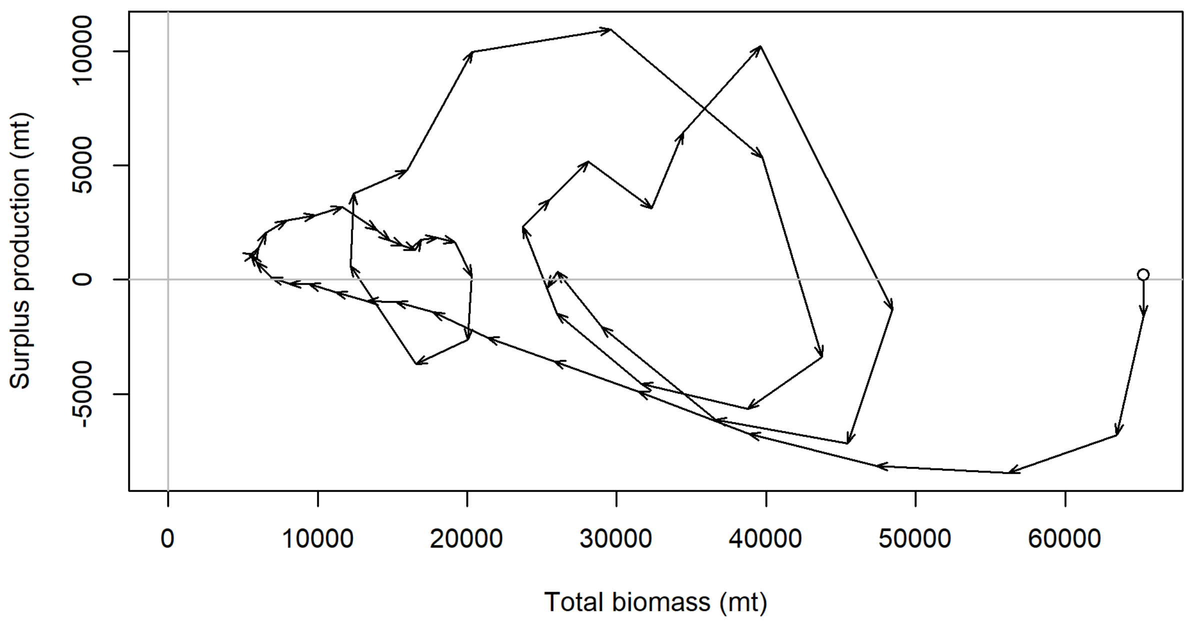


Figure 23. Vendace SD 31. Surplus production against biomass plot. The round circle represents the first year of the time series (1965).

When all diagnostic tests are considered together, the power to detect model misspecification improves without a substantial increase in the probability of incorrectly rejecting a correctly specified model (Carvalho et al., 2017, 2021) and therefore these diagnostics should be all applied routinely. When the criteria for rejecting a model as correctly specified is a failure of at least one of the diagnostic tests, nearly 90% of most mis-specified are detected with no real increase in the probability of a false detection (Carvalho et al., 2017, 2021). Residual analyses were easily the best detector of misspecification of the observation model, while the retrospective analysis had low rates of detection of mis-specified models (Carvalho et al., 2017, 2021), although retrospective analysis is effective in detecting un-modeled temporal variation (Hurtado-Ferro et al., 2014). Finally, opposed to the widely used maximum-likelihood estimator, MCMC gives clear warning signs when a non-identifiable model is used for fitting (Siekmann et al., 2012). In this context, we created a table that summarize all diagnostics for the base case model (Table 7). The table is an attempt to sum up a multidimensional space and thus it needs to be seen as a guidance more than as a definitive result. However, it is evident from Table 7 that the base case model has a good pass of most of the key diagnostic tests performed. Thus, the base case model was proposed as the model to be used to integrate the key dimensions of uncertainty in the ensemble.

Table 7. Vendace SD 31. Summary table of the diagnostics of the base case model. "Passed tests" score refers to the average test passes in % when multiple tests have been conducted.

Diagnostic	**Indicator**	**Component**	*Model* **Reference**
Convergence		Model	6.90E-05
N. of parameters		Model	218
Hessian		Model	Yes
Jittering (10%)	% of runs above reference LL	Local minima	100%
	N of converged runs not different from reference run	Model	100%
Retrospective (5 years)	Mohn´s rho	SSB	0.16
		F	-0.18
Hindcasting	MASE	Survey	Pass
		CPUE	Pass
MCMC	Confidence of intervals of SSB_{2020}	Model	Pass
Run´s test		Survey	Pass
		CPUE	Pass
		Length compositions	Pass
		RMSE survey	Fail
		RMSE lenght compositions	Pass
		Passed tests	92.9%

Trends in SSB, F and R of the reference model

The stock status and the trends in SSB, R and F are based on the MLE model. The spawning stock biomass (SSB) has been declining from the beginning of the time series up to the 1980s, then it increased during the 1980s reaching its peak in 2010s and declining thereafter but still at levels large than the biomass target (i.e. $B_{40\%}$). Fishing mortality (F) has increased markedly from the beginning of the times series up to 1980s and declined thereafter to remain at levels below the F target (i.e. F that corresponds to $B_{40\%}$). Recruitment (R) shows the tendency for the stock to produce larger years' class than expected in the latest 20 years. In 2013 a very strong year class appeared (Figure 24).

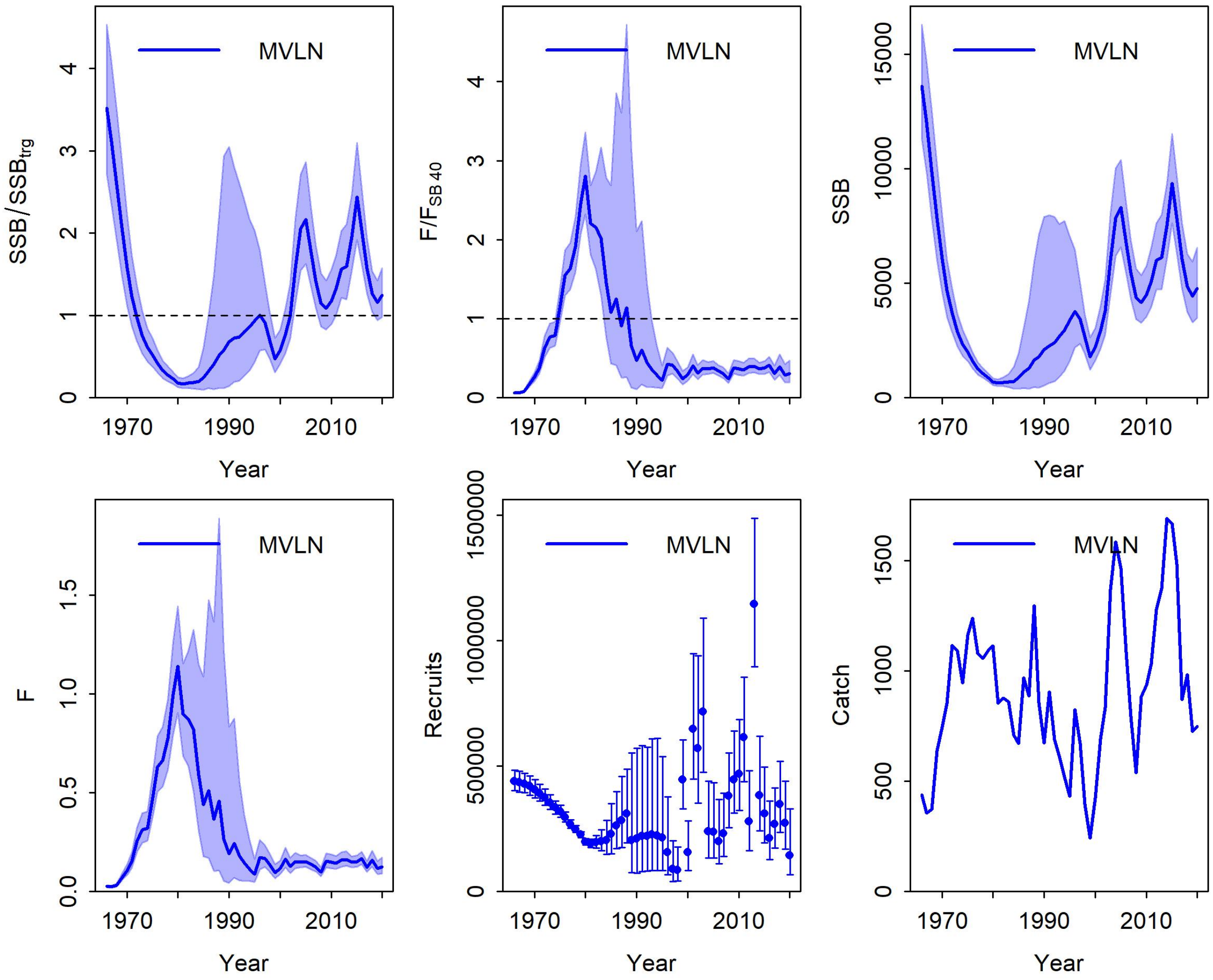


Figure 24. Vendace SD 31. Summary of the stock assessment. SSB, F and R with 95% confidence intervals. Catches by fleet and SSB are in tonnes R is in thousands of individuals.

Medium-term projections

Not relevant.

Long-term projections

Not relevant.

Appropriate Reference Points (MSY)

The reference points were set following analyses recently conducted at WKREF1 (ICES 2021). The analysis compared the ICES system to derive reference points (which has been used in the past for deriving reference points for vendace) against a set of alternative candidates based on biological principles, international standards and best practice for a set of 64 species assessed by ICES using size structured assessment models. The results of the analysis showed that for high productive species as vendace (i.e. vendace has a productivity index score = 0.55; productivity index score combines generation time and stock productivity), the target F should be set at the F that brings the stock at SSB equal to 45% of B_0 (which is now defined as the target biomass reference point, B_{trg}) and the trigger point (i.e. $B_{trigger}$) should be set equal to B_{trg}. B_{lim} is set to 10% of B_0 in all simulations (Figure 25-27). This set of reference points achieves the same or larger long term catches than any other tested but has a smaller probability of the biomass falling below B_{lim} and a larger probability of reaching the B target.

Thus, to sum up, $B_{45\%}$ is proposed as the biomass target (B_{trg}), $F_{45\%}$ as the F_{MSY} proxy, B_{lim} is set at 10% of B_0 and $B_{trigger}$ as B_{trg}.

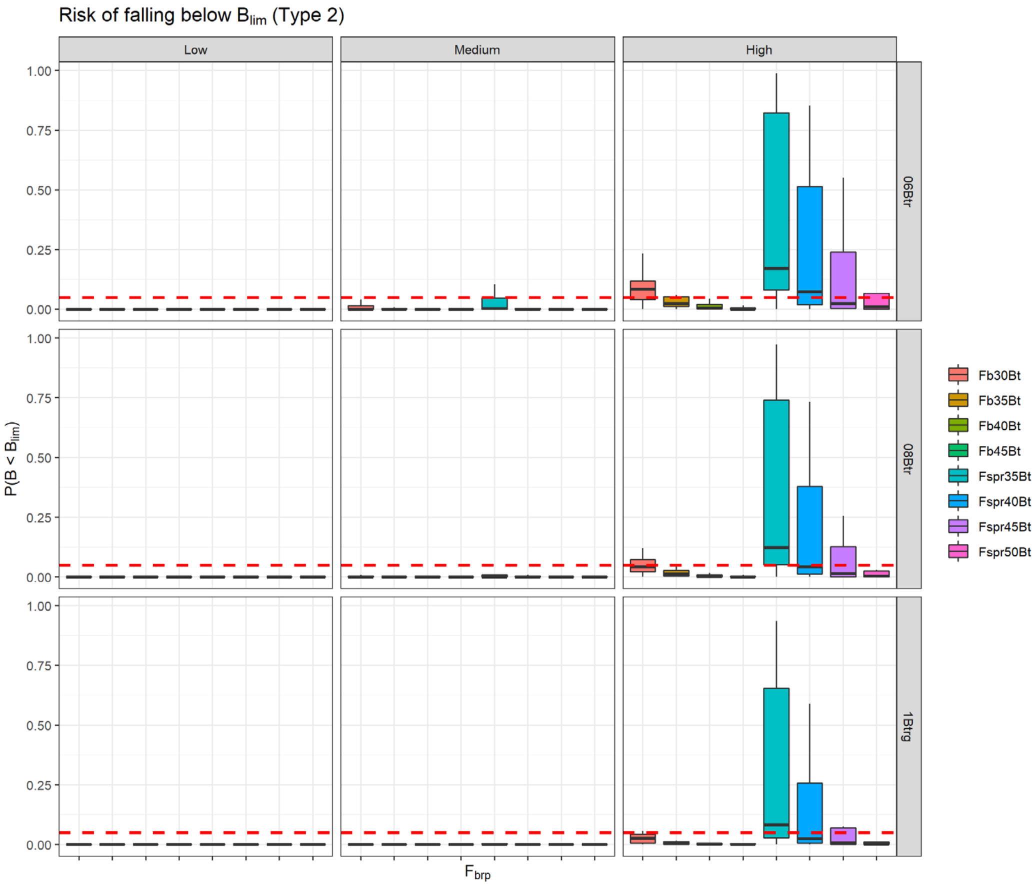


Figure 25. Risk of falling below B_{lim} (i.e. 10% of B0) for low, medium and high productivity species for different combinations of F target and $B_{trigger}$.

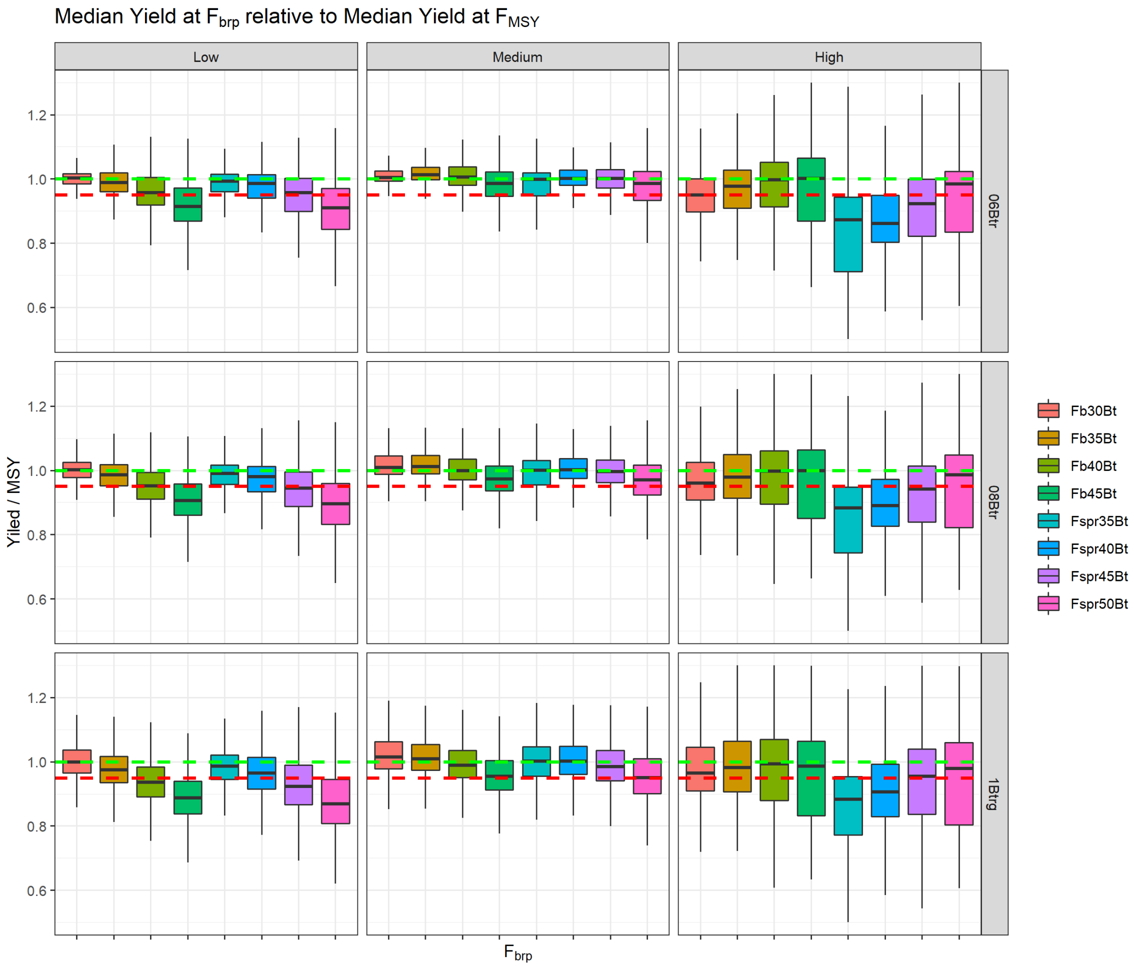


Figure 26. Median yield relative to yield at MSY, for low, medium and high productivity species for different combinations of F target and $B_{trigger}$.

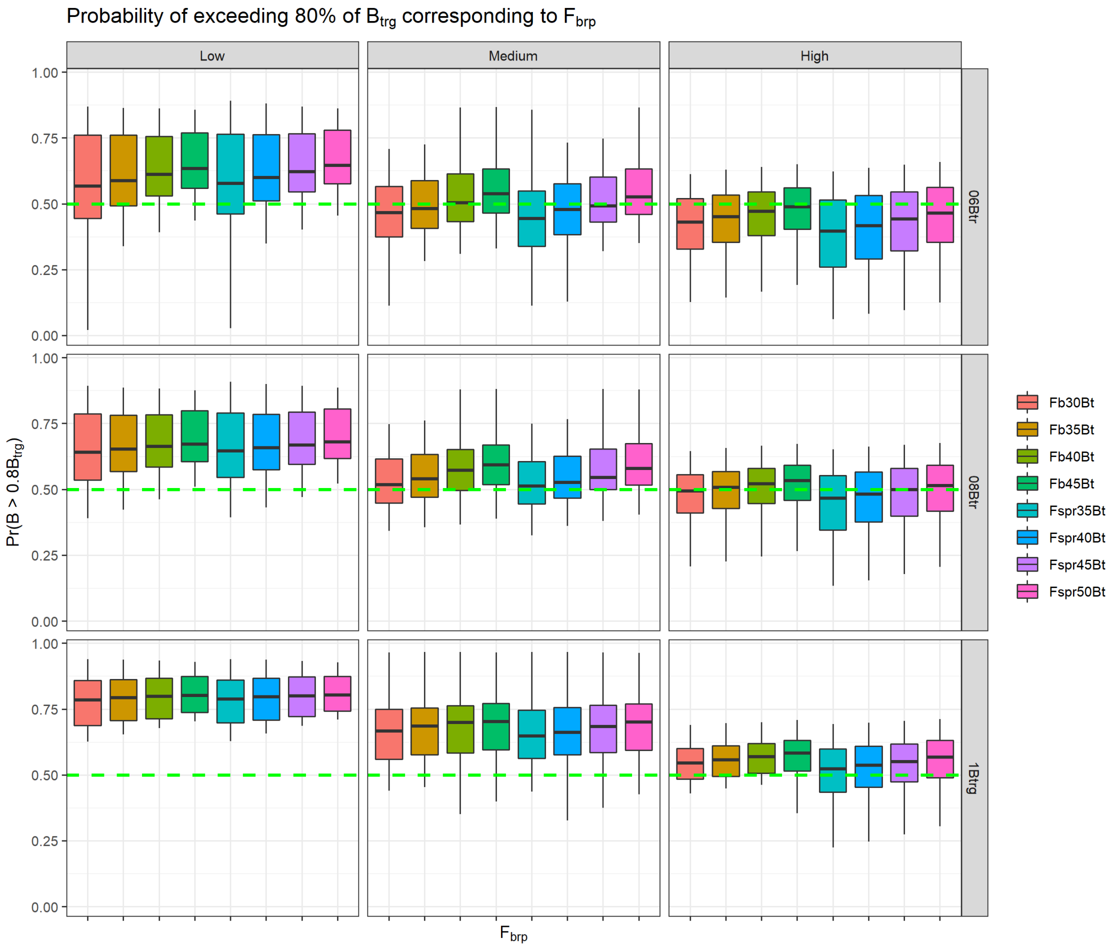


Figure 27. Probability of exceeding 80% of B target corresponding to F target for low, medium and high productivity species for different combinations of F target and $B_{trigger}$.

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Appendices

Appendix I

GLOSSARY OF TERMS AND ACRONYMS USED IN THIS DOCUMENT

B_0: The unfished equilibrium female spawning biomass.

B_{MSY}: The estimated female spawning biomass which theoretically would produce the maximum sustainable yield (MSY) under equilibrium fishing conditions (constant fishing and average recruitment in every year).

B_{lim}: Spawning biomass below which recruitment is considered to be impaired.

Catchability (q): The parameter defining the proportionality between a relative index of stock abundance (often a fishery-independent survey) and the estimated stock abundance available to that survey (as modified by selectivity) in the assessment model.

Catch-per-unit-effort (CPUE): A raw or (frequently) standardized and model-based metric of fishing success based on the catch and relative effort expended to generate that catch from commercial or survey estimates. Catch per-unit-effort is often used as an index of stock abundance.

Cohort: A group of fish born in the same year. Also see recruitment and year-class.

CV: Coefficient of variation. A measure of uncertainty defined as the standard deviation (SD) divided by the mean.

Fishing mortality rate, or instantaneous rate of fishing mortality (F): A metric of fishing intensity that is usually reported in relation to the most highly selected ages(s) or length(s), or occasionally as an average over an age range that is vulnerable to the fishery.

F_{MSY}: The rate of fishing mortality estimated to produce the maximum sustainable yield (MSY) from the stock.

Markov-Chain Monte-Carlo (MCMC): A numerical method used to sample from the posterior distribution (see below) of parameters and derived quantities in a Bayesian analysis. It is more computationally intensive than the maximum likelihood estimate (see below), but provides a more accurate depiction of parameter uncertainty.

Maximum likelihood estimate (MLE): A method used to estimate a single value for each of the parameters and derived quantities. It is less computationally intensive than MCMC methods (see below), but parameter uncertainty is less well determined.

Maximum sustainable yield (MSY): An estimate of the largest sustainable annual catch that can be continuously taken over a long period of time from a stock under equilibrium ecological and environmental conditions.

NUTS: Hamiltonian Monte Carlo (HMC) is a Markov chain Monte Carlo (MCMC) algorithm that avoids the random walk behaviour and sensitivity to correlated parameters that plague many MCMC methods by taking a series of steps informed by first-order gradient information. These features allow it to converge to high-dimensional target distributions much more quickly than simpler methods such as random walk Metropolis or Gibbs sampling. No-U-Turn Sampler (NUTS), an extension to HMC that eliminates the need to set a number of steps. NUTS uses a recursive algorithm to build a set of likely candidate points that spans a wide swath of the target distribution, stopping automatically when it starts to double back and retrace its steps.

Posterior distribution: The probability distribution for parameters or derived quantities from a Bayesian model representing the result of the prior probability distributions being updated by the observed data via the likelihood equation. For stock assessments, posterior distributions are approximated via numerical methods; one frequently employed method is MCMC.

Prior distribution: Probability distribution for a parameter in a Bayesian analysis that represents the information available before evaluating the observed data via the likelihood equation. For some parameters, non-informative priors can be constructed which allow the data to dominate the posterior distribution (see above). For other parameters, informative priors can be constructed based on auxiliary information and/or expert knowledge or opinions.

R0: Estimated annual recruitment at unfished equilibrium.

Recruits/recruitment: the estimated number of new members in a fish population born in the same age. In this assessment, recruitment is reported at age 0. See also cohort and year class.

Recruitment deviation: The offset of the recruitment in a given year relative to the stock-recruit function; values occur on a logarithmic scale and are relative to the expected recruitment at a given spawning biomass (see below).

Random Walk Metropolis: In statistics and statistical physics, the Metropolis–Hastings algorithm is a Markov chain Monte Carlo (MCMC) method for obtaining a sequence of random samples from a probability distribution from which direct sampling is difficult. This sequence can be used to approximate the distribution (e.g. to generate a histogram) or to compute an integral (e.g. an expected value). Metropolis–Hastings and other MCMC algorithms are generally used for sampling from multi-dimensional distributions, especially when the number of dimensions is high.

SD: Standard deviation. A measure of variability within a sample.

Steepness (h): A stock-recruit relationship parameter representing the proportion of R0 expected (on average) when the female spawning biomass is reduced to 20% of B0 (i.e., when

Stock Synthesis (SS): The age-structured stock assessment model applied in this stock assessment.

Year-class: A group of fish born in the same year. See also ‘cohort’ and ‘recruitment’.

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2021-11-30

WD 6: Ringed seal predation on vendace in the Bothnian Bay

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Introduction

The purpose of this working document is to present the available data and the logic behind the calculations of the amount and size distribution of vendace (*Coregonus albula*) consumed by the Bothnian Bay ringed seal (*Pusa hispida*) population.
First, a short introduction about the biology of the ringed seal is given and then the data and the assumptions made for the different steps conducted in the calculations of consumption of vendace by ringed seals is presented.
The steps are:

1) Estimation of the total ringed seal population size and the population development 1980-2020.
2) The distribution of ringed seals in the Bothnian Bay vs. the Bothnian Sea and estimation of the number of seals in the Bothnian Bay based on telemetry data.
3) The proportion of vendace and the length frequency distribution of vendace in the ringed seal diet.

The above steps are then the basis for calculating the overall consumption of vendace by year and quarter.

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Ringed seal biology.

Ringed seals are mainly found in the Arctic, but land-locked sub populations exist as geographically isolated postglacial relicts, not only in the Baltic Sea, but also in the lakes Ladoga (*P.h. ladogensis*) and Saimaa (*P.h. saimensis*) as well as in the Caspian Sea (*P. caspica*) and lake Baikal (*P. sibirica*). Ringed seals grow to an average length of 1.5–1.75 meters and a mass of less than 120 kilograms, and can reach a maximum age of over 40 years. Females become sexually mature between 3 and 6 years after which they normally generate one pup every year. The main pupping season for the ringed seal in the Baltic occurs between mid-February and early March, followed by the annual moult, peaking between end of April and beginning of May, which is considerably earlier as compared with Arctic ringed seals.

The Baltic ringed seal population in the beginning of the 20th century have been estimated to approximately 200,000 animals, but decreased dramatically to 25,000 before 1940 as a consequence of an extermination campaign, predominantly administrated by Swedish and Finnish authorities. Thereafter, the ringed seal population was further reduced by physiological consequences from environmental pollutants. (Bergman and Olsson, 1986, Helle, 1986, Hårding and Härkönen, 1999, Kokko *et al.*, 1999). The ringed seal population in the Baltic Sea is distributed between three areas: The Gulf of Bothnia, the Gulf of Finland and the Gulf of Riga (Härkönen *et al.*, 1998). The Gulf of Bothnia subpopulation is the most numerical population, and from the 1980s minimum level, that population has increased by approximately 4.5 % per year.

Ringed seal population size

Following sporadic surveys in 1975, 1978 and 1988 (Helle, 1980, Helle, 1986), the Gulf of Bothnia ringed seal population have been monitored on an annual basis since 1988. Surveys are carried out in the Bothnian Bay during moulting period, in mid-April to early May, when the seals spend more time on the ice to increase their skin temperature and promote the moulting process (Feltz and Fay, 1966). During this time, ringed seals are generally spread out on the sea ice, close to breathing holes, lairs and cracks and leads in the ice. Aerial line-transect surveys using a line-transect methodology, with survey strips covering a width of 800 m (400 on each side of the plane), evenly distributed over the ice covered area are designed to cover a minimum of 13% of the entire ice covered sea area (Härkönen and Heide-Jørgensen, 1990, Härkönen and Lunneryd, 1992, Härkönen *et al.*, 1998). The exact proportion of the ice covered with the survey strips varies between years. From having only been counted during the survey, all seals within the survey strips are since 2015 photographed and their numbers are subsequently counted from the pictures. The number of seals hauling out on the ice is calculated by extrapolating/multiplying the number of seals on the survey strips to the entire ice-covered area (Fig. 1).

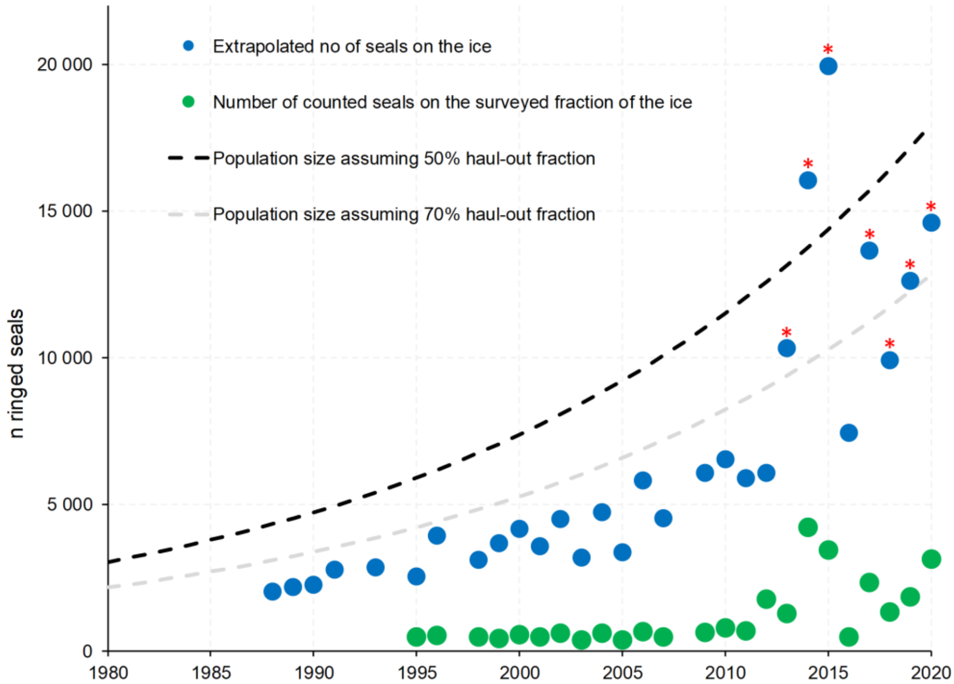

Figure 1. Number of ringed seals counted in the aerial line-transect surveys (green circles), extrapolated number of seals on the ice (blue circles) and estimated population size based on the population growth trend 1988-2012, assuming a haul out fraction of 70% (grey dotted line) and 50 % (black dotted line). The red asterisks define years with anomalous ice conditions and accompanying incomparably high estimates of seals on the ice, and were thus excluded from the trend-curve calculation.

Prevailing ice-conditions have been shown to significantly affect the survey results. The surveys during 1988-2012 are considered to have been carried out under normal ice conditions, with seals widely distributed over large areas with stable ice conditions. The ice cover during more recent surveys (years 2013-2015; 2017-2020) have been characterized by less intact ice cover, ice break-up before or during the survey period and more heterogeneous ice conditions, which has resulted in a completely different pattern of distribution with more seals entering the ice to form larger haul-out groups. This is assumed to be a result of behavioural changes in the seal population during conditions with reduced ice cover and earlier ice break-up and these ice-condition related behavioural changes have led to anomalous estimates on seal numbers. The theory is that the haul-out fraction during the survey period in normal years is relatively small, albeit unknown, and dominated by adult seals, whereas the haul-out fraction during anomalous years is relatively large, with larger numbers of younger seals hauling out together with the adult seals (Pers. comm. Markus Ahola, Swedish Museum of Natural History). Consequently, the estimated number of seals on the ice during the time of surveys in anomalous years has increased drastically, with several times as many seals compared to earlier years with normal ice conditions (Fig. 1). Years 2016 and 2018 are not far from the normal level. However, the sample of the ice-covered area was low in 2016 due to very little, already broken up, ice which was about to disappear. The low sample size causes increased uncertainty as such and ice-conditions similar to what was observed in 2016 had given exceptional results in earlier years. In 2018, the ice-conditions were relatively normal and relatively few groups, compared the clearly exceptional years, were observed. However, since a proper understanding of the behaviour of the seals is lacking, it is impossible to say if this single year in between exceptional years is comparable with the earlier normal years. Including 2018 would slightly increase the growth rate of the population. This would be contradictory with the expected decreasing effect of poor ice-winters (supposedly causing reduced reproductive success) and increased hunting to the population growth. This contradiction increases the uncertainty of the judgement for 2018 and it was therefore excluded too from the population-trend estimation. The interpretation of the results, however, is that the total population size is larger than previously thought (HELCOM, 2018). Ice-quality related differences in haul-out behaviour between age groups of ringed seals have been observed also in other areas (Moulton *et al.*, 2002, Crawford *et al.*, 2012). More data is needed to understand relationships between haul-out behaviour and ice conditions and to be able to improve estimates on the populations size of the ringed seal population in the Gulf of Bothnia.

Haul-out fraction

The number of seals visible on the ice is a proportion of the total population size. This proportion is assumed to depend on the prevailing ice distribution (surface area and quality) and behaviour of the seals, in combination with weather conditions and time of the day (Chambellant *et al.*, 2012). Sexually immature seals are believed to be under-represented in the census results in years with 'normal' ice distribution, when the fraction of seals visible on the ice is considered to be dominated by adult individuals. No studies have been carried out on the haul-out fraction of ringed seals in the Bothnian Bay, and thus no 'correction factor' to account for seals not visible on the ice (being either in the water or in lairs under the snow) to be able to estimate the true population size exists. Also from other areas, such information is scares. Based on literature data, haul-out fractions during the moulting period range from less than half of the population size to over 80% (Table 1).

Table 1. Haul-out fractions of ringed seals during moult.

Haul-out fraction during moult	**Reference**
83-84%	(Fedoseev, 1971)
50%	(Smith, 1973)
70%	(Finley, 1979)
48% (23-80%)	(Smith and Hammill, 1981)
50-75%	(Hammill and Smith, 1990)
43%	(Kelly and Quakenbush, 1990)
50%	(Stirling and Øritsland, 1995)
57% (33-92%)	(Born *et al.*, 2002)
60-68%	(Bengtson *et al.*, 2005)
40-80%	(Carlens *et al.*, 2006)
42% (36-52%)	(Krafft *et al.*, 2006)
55%	(Kelly *et al.*, 2010)

Estimation of population size

Based on literature data, we decided to use an upper level of the population size, assuming that the estimated numbers of seals on the ice represent 50% of the true population size, and a lower level, assuming that the estimated numbers on the ice represent 70% of the true population size (Table 1). The estimated numbers of seals on the ice were calculated from a trend line based on the 'normal' period 1988-2012, and the numbers of seals on the ices during 2013-2020 (i.e. the 'anomalous' period) were assumed to follow the same trend. The upper and lower levels were calculated by dividing the trend-based estimated number of seals on the ice with 0.5 and 0.7, respectively, for each year (Fig. 1). We also calculated an intermediate level, assuming a haul-out fraction of 60%. Upper and lower levels of the estimated population size during 1988-2020 is presented in table 2.

Distribution and movements of ringed seals in the Gulf of Bothnia and proportion of time spent in the Bothnian Bay

While an earlier telemetry study of spatial ecology of ringed seals in the Gulf of Bothnia showed that the seals stayed in the basin they were tagged, a more recent, and larger, study clearly indicated that ringed seals tagged in the Bothnian Bay migrated both to the Bothnian Sea and further (Härkönen *et al.*, 2008, Oksanen *et al.*, 2015).

To get an estimation of the proportion of the Gulf of Bothnia occurring in the Bothnian Bay, and thus overlapping spatially with the Bothnian Bay vendace stock, we used ssatellite telemetry data from 30 ringed seals captured in the Bothnian Bay during autumn in 2011–2013 (Oksanen *et al.*, 2015) (Mervi Kunnasranta, Natural Resources Institute (Luke), Finland). The proportion of time spent in Bothnian Bay (tagging records with latitude ≥ 63.5) was calculated by quarter as well as for the quarters aggregated for each seal as:

$$\text{Proportion of time spent in Bothnian Bay} = \frac{\text{n days spent in Bothnian Bay}}{\text{n days recorded}}$$

The seasonal distribution of the tagged seals is presented in table 2. Based on these results, we assumed three levels of ringed seal-vendace overlap in the Bothnian Bay: 50%, 60% and 70%.

Table 2. Average proportion of time spent by ringed seals in the Bothnian Bay by quarters (Q) and quarters aggregated (All quarters). Numbers in brackets show the number of seals used in the calculations.

	Q1	Q2	Q3	Q4	All quarters
Proportion of time spent in the Bothnian Bay	0.44 (n=27)	0.80 (n=5)	0.79 (n=6)	0.64 (n=30)	0.59 (n=30)

By combining estimates of the Gulf of Bothnia ringed seal population size (Figure 1) and proportion of time spent in the Bothnian Bay, i.e. overlapping with the vendace stock (Table 1) we calculated three levels of time series of the number of ringed seals in the Bothnian Bay (Table 3). The lower level assumed a haul-out fraction of 70% and a low (50%) overlap with vendace. The upper level assumed a haul-out fraction of 50% and a high (70%) overlap with vendace. The intermediate level assumed a haul-out fraction of 60% and mid (60%) overlap with vendace, similar to both a 50% haul-out fraction and 50% overlap and a 70% haul-out fraction and 70% overlap.

Table 3. Estimated number of seals in the Bothnian Bay 1980-2020, based on different levels of haul-out fraction during the moult survey and proportion of time spend in the Bothnian Bay (vendace overlap).

	Number of ringed seals in the Bothnian Bay		
Year	**Lower level (70% haul out, 50% overlap)**	**Intermediate level (60% haul out, 60% overlap)**	**Upper level (50% haul out, 70% overlap)**
1980	1084	1517	2124
1981	1133	1586	2220
1982	1185	1658	2321
1983	1238	1733	2426
1984	1295	1812	2537
1985	1353	1894	2652
1986	1415	1980	2772
1987	1479	2070	2898
1988	1547	2165	3031
1989	1617	2263	3168
1990	1690	2366	3312
1991	1767	2473	3462
1992	1847	2586	3620
1993	1931	2703	3784
1994	2019	2826	3956
1995	2111	2955	4137
1996	2207	3089	4325
1997	2307	3229	4521
1998	2412	3376	4726
1999	2522	3530	4942
2000	2636	3690	5166
2001	2756	3858	5401
2002	2881	4033	5646
2003	3012	4217	5904
2004	3150	4409	6173
2005	3292	4609	6453
2006	3442	4818	6745
2007	3599	5038	7053
2008	3762	5267	7374
2009	3933	5506	7708
2010	4112	5756	8058
2011	4299	6018	8425
2012	4495	6292	8809
2013	4699	6578	9209
2014	4912	6877	9628
2015	5135	7189	10065
2016	5369	7516	10522
2017	5613	7858	11001
2018	5868	8215	11501

2019	6135	8588	12023
2020	6414	8979	12571

Diet analysis

Stomachs and intestines (2007-2009: the whole intestine, post 2009: colon only) were examined from ringed seals collected from the Swedish and Finnish (2019, 2020) research and protection hunt in the Bothnian Bay between 2007 and 2020. Samples were collected by SLU and the Swedish Museum of Natural History in Sweden and Luke in Finland. Samples were stored in plastic bags at -20°C until examination. The recovery and identification of hard-part prey remains in the digestive tract contents followed standard procedures (Pierce and Boyle, 1991, Bowen and Iverson, 2012). A subsample for subsequent DNA analysis was taken from the majority of the samples. Otoliths constituted the bulk of prey remain items used for identification of prey species, and each otolith was assumed to represent ½ fish. Other prey remains used were whole individuals, other skeletal parts and exoskeleton from crustaceans. Length and weight of consumed fish were estimated from species-specific regression equations. For herring (*Clupea harengus*), fourhorned sculpin (*Myoxocephalus quadricornis*), smelt (*Osmerus eperlanus*) and sprat (*Sprattus sprattus*), we used regression equations from Lundström et al. (2010, 2014). For vendace (*Coregonus albula*) and whitefish (*Coregonus lavaretus*), we used regression equations based on a collection of otoliths from the Bothnian Bay (SLU, unpublished data) and for the remaining fish species, we used regression equations from (Leopold *et al.*, 2001). Individuals of three-spined stickleback (*Gasterosteus aculeatus*) and *Saduria* (*Saduria entomon*) were assumed to have a weight of 2 g (Haahtela, 1990, Jurvelius *et al.*, 1996, Ejdung and Bonsdorff, 2001). Size correction, to compensate for digestive erosion of otoliths (erosion grade 2 and 3), was implemented using species and erosion-grade specific size correction factors based on the mean size of otoliths from the different erosion grade categories (Lundström *et al.*, 2007).

Accounting for possible mis-identification of vendace/whitefish otoliths

Species assignment from seal diet samples using shape analyses in a machine learning framework

(Mion M., Berg F., Saltalamacchia F., Bartolino V., Lövgren J., Bergenius Nord M., Lundström K.)

Introduction

The species in the *Coregonus* genus have very similar otoliths (Suuronen and Lehtonen, 2012), thus distinguishing between vendace (*C. albula)* and whitefish (*C. lavaretus*) otoliths in ringed seal diet samples has been so far challenging, introducing possible bias to the diet results (i.e. overestimating or underestimating the number of vendace and whitefish in the seal diet). To tackle this issue, we used otolith shape analyses in combination with machine learning techniques to discriminate between vendace and whitefish otoliths and assign the correct species to individual otoliths previously classified as *Coregonus* genus from ringed seals diet samples.

Material and methods

The analytical framework was built using the "assignPOP" package (Chen et al., 2017) in R (R Core Team, 2017). To accurately assign a species to otoliths collected from ringed seal stomach samples we build a baseline data used to develop classification functions. The baseline consisted of two datasets: 1) shape coefficients extracted from whole otoliths of known species (i.e. vendace and whitefish) and 2) shape coefficients extracted from otoliths of vendace and whitefish chemically eroded in order to mimic the 3 different erosion stages encountered in otoliths found in seal stomachs (see (Tollit *et al.*, 1997) for erosion stage cassification).

For the first dataset, stored dry otoliths of vendace and whitefish were available and retrieved from collections belonging to the Department of Aquatic Resources of the Swedish University of Agricultural Sciences. Only otoliths without signs of damage were used and pictures from 373 otoliths for vendace and 251 otoliths for whitefish were taken. The shape analyses were carried out following the procedure illustrated by Libungan and Pálsson (2015). A total of 64 independent wavelet shape coefficients were calculated for each otolith describing its outline.

For the second dataset we performed an *in vitro* digestion of the otoliths. To simulate the 3 different erosion stages found in the seal stomach, the otoliths were maintained in a solution of pH 1.5 hydrochloric acid at a constant temperature of 37 °C for 30 minutes intervals up to 150 minutes (T1=0 min, T2=30 min, T3=60 min, T4=90 min, T5=120 min, T6=150 min). After the completion of each experimental batch (T1, T2, T3, T4, T5, T6), the otoliths were washed with distilled water, photographed and re-measured, and shape indices extracted. In total 53 otoliths for vendace and 50 otolith for whitefish were chemically eroded.

Two resampling, cross-validation procedures, Monte-Carlo (Xu & Liang, 2001) and K-fold (Rodriguez, Perez, & Lozano, 2010) were used to test the accuracy of species assignment of the baseline (Chen et al., 2017). For both Monte-Carlo and K-fold cross-validations the support vector machine classification model is used to build the predictive model (Chen et al., 2017).

Pictures of 778 otoliths classified as *Coregonus* family from the stomach of 30 ringed seals collected between 2008 and 2020 in the Bothnian Bay were taken and the shape coefficient were extracted in order to perform species assignment. Only otoliths from stomach samples with an assignment probability >75% were considered in the calculation of the proportion between vendace and whitefish in ringed seal diet.

Results

The overall assignment accuracies based on the Monte-Carlo cross-validation and K-folds were above 90% and thus deemed satisfactory for assigning a species to unknown otolith samples.

The predictive model was able to assign a species to 89% of the otoliths collected from stomach samples with an assignment probability >75%. Overall the average proportions of otoliths assigned to vendace and whitefish were 78% and 22%, respectively (Table 4).

Table 4. Average proportion of vendace and whitefish in otoliths classified as *Coregonus* family in ringed seal diet samples. In brackets is reported the number of seal stomach samples used in the calculation.

Year	Proportion assigned to vendace	Proportion assigned to whitefish
2008 (n=10)	0.79	0.21
2015 (n=10)	0.86	0.14
2020 (n=5)	0.51	0.49
2008-2020 (n=30)	0.78	0.22

To account for possible mis-identification of whitefish otoliths in stomach samples, we used the average numerical proportion of 22% whitefish otoliths (Table 4). By calculating weights of vendace (20 g) and whitefish (18 g) from the average size of otoliths identified as vendace (1.8 mm), the weight proportion of vendace was estimated as 20%. Consequently, original weight proportions of vendace in the diet was multiplied with 0.8 to account for possible mis-identification of whitefish otoliths among the vendace otoliths.

Consumption of vendace by ringed seals in the Bothnian Bay

We chose years from which we had at least 30 samples containing prey remains as our reference years (2008, 2015, 2019 and 2020) and calculated the average weight proportion of vendace per quarter (Q). No samples were available from Q1 since no hunting is allowed during that period, and the proportion of vendace in Q1 was assumed to be the same as in Q2. Due to low sample sizes (n<5) in Q3 year 2008, 2015 and 2020, and Q4 year 2019, the weight proportions of vendace in Q3 and Q4 were assumed to be the same Table 5).

Table 5. Average quarter-specific weight proportions of vendace in the ringed seal diet in the reference years 2008, 2015, 2019 and 2020. Numbers within brackets show the number of samples.

Year	**Q1-Q2**	**Q3-Q4**
2008 (n=57)	0.23	0.59
2015 (n=34)	0.23	0.54
2019 (n=45)	0.02	0.35
2020 (n=103)	0.07	0.20

The quarter-specific changes in vendace weight proportions between the reference years 2008-2015 and 2015-2019 were assumed to follow a linear increase or decrease. The quarter-specific vendace weight proportions 1980-2007 were assumed to be equal to 2008, due to lack of data.

The individual prey consumption ($kg * seal^{-1} * day^{-1}$) was calculated using a simple energy consumption model according to:

$$\mathbf{E\ (kJ * day^{-1}) = BM * A * ME^{-1}}$$

BM = Basal metabolism = $293 * \text{body weight}^{0.75}$ (Kleiber, 1961)

A = Activity factor, accounting for energy costs of various activities, set to 2 (Ryg and Øritsland, 1991, Boyd, 2002).

ME = Proportion of the consumed energy available for metabolism, set to 0.85 (Ashwell-Erickson and Elsner, 1981, Ronald *et al.*, 1984).

The energy requirement was calculated for an average ringed seal of 50 kg, based on the median weight of 64 ringed seals collected from the Gulf of Bothnia, data available from the Swedish Museum of Natural History, assumed to represent the energy requirement throughout the year. Energy content of the diet was assumed to be 5,5 MJ $*$ kg^{-1} and similar for all species (Aneer, 1975, Penczak *et al.*, 1984, Rudstam, 1988, Helminen *et al.*, 1990, Kemper, 1995, Muje *et al.*, 1997). The daily energy requirement was calculated to 13 MJ, representing a prey biomass consumption of 2.4 kg. Consequently, the annual prey consumption was 876 kg (219 kg $*$ quarter^{-1}).

The year- and quarter-specific consumption of vendace by the ringed seal population in the Bothnian Bay (Figure 2) was calculated by multiplying the weight proportions (Table 5) with the individual biomass consumption and the upper, intermediate and lower levels of the population size (Table 3, Table 6).

Table 6. The year- and quarter-specific consumption of vendace (ton) by the ringed seal population in the Bothnian Bay.

	Lower level (70% haul-out, 50% overlap)				Intermediate level (60% haul-out, 60% overlap)				Upper level (50% haul-out, 70% overlap)			
Year	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1980	54	54	141	141	76	76	197	197	106	106	276	276
1981	56	56	147	147	79	79	206	206	111	111	289	289
1982	59	59	154	154	83	83	216	216	116	116	302	302
1983	62	62	161	161	86	86	225	225	121	121	315	315
1984	65	65	168	168	90	90	236	236	126	126	330	330
1985	67	67	176	176	94	94	246	246	132	132	345	345
1986	71	71	184	184	99	99	257	257	138	138	360	360
1987	74	74	192	192	103	103	269	269	144	144	377	377
1988	77	77	201	201	108	108	281	281	151	151	394	394
1989	81	81	210	210	113	113	294	294	158	158	412	412
1990	84	84	220	220	118	118	308	308	165	165	431	431
1991	88	88	230	230	123	123	321	321	173	173	450	450
1992	92	92	240	240	129	129	336	336	180	180	471	471
1993	96	96	251	251	135	135	351	351	189	189	492	492
1994	101	101	262	262	141	141	367	367	197	197	514	514
1995	105	105	274	274	147	147	384	384	206	206	538	538
1996	110	110	287	287	154	154	402	402	216	216	562	562

1997	115	115	300	300	161	161	420	420	225	225	588	588
1998	120	120	314	314	168	168	439	439	236	236	614	614
1999	126	126	328	328	176	176	459	459	246	246	642	642
2000	131	131	343	343	184	184	480	480	257	257	672	672
2001	137	137	358	358	192	192	502	502	269	269	702	702
2002	144	144	375	375	201	201	524	524	281	281	734	734
2003	150	150	392	392	210	210	548	548	294	294	767	767
2004	157	157	409	409	220	220	573	573	308	308	802	802
2005	164	164	428	428	230	230	599	599	322	322	839	839
2006	172	172	447	447	240	240	626	626	336	336	877	877
2007	179	179	468	468	251	251	655	655	351	351	917	917
2008	**187**	**187**	**489**	**489**	**262**	**262**	**685**	**685**	**367**	**367**	**959**	**959**
2009	196	196	505	505	275	275	707	707	385	385	990	990
2010	206	206	521	521	288	288	730	730	404	404	1021	1021
2011	216	216	538	538	302	302	753	753	423	423	1054	1054
2012	226	226	555	555	317	317	777	777	443	443	1088	1088
2013	237	237	573	573	332	332	802	802	465	465	1123	1123
2014	248	248	591	591	348	348	827	827	487	487	1158	1158
2015	**260**	**260**	**609**	**609**	**364**	**364**	**853**	**853**	**510**	**510**	**1194**	**1194**
2016	210	210	582	582	293	293	814	814	411	411	1140	1140
2017	154	154	551	551	215	215	771	771	301	301	1079	1079
2018	92	92	515	515	129	129	721	721	180	180	1010	1010
2019	**25**	**25**	**476**	**476**	**35**	**35**	**666**	**666**	**48**	**48**	**932**	**932**
2020	**94**	**94**	**283**	**283**	**132**	**132**	**396**	**396**	**185**	**185**	**555**	**555**

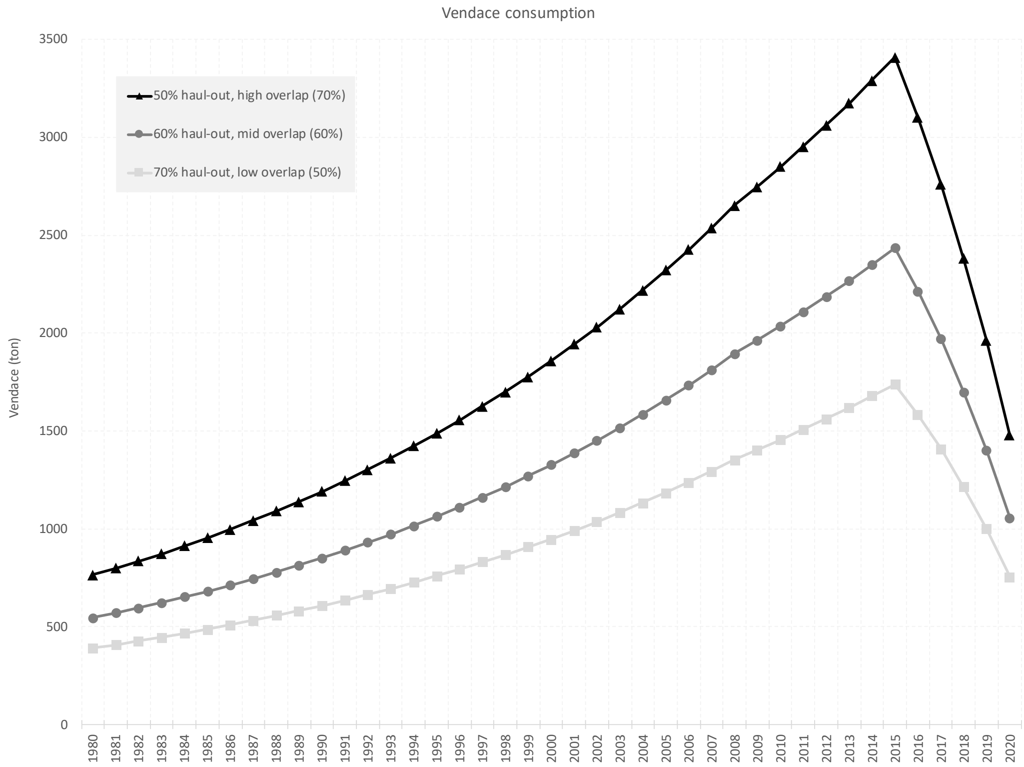

Figure 2. Annual consumption of vendace (ton) by the ringed seal population in the Bothnian Bay.

Length frequency distributions of vendace in diet

The length frequency distribution of vendace in the seal samples from the reference years 2008, 2015, 2019 and 2020 was estimated from size corrected otoliths (Figure 3).

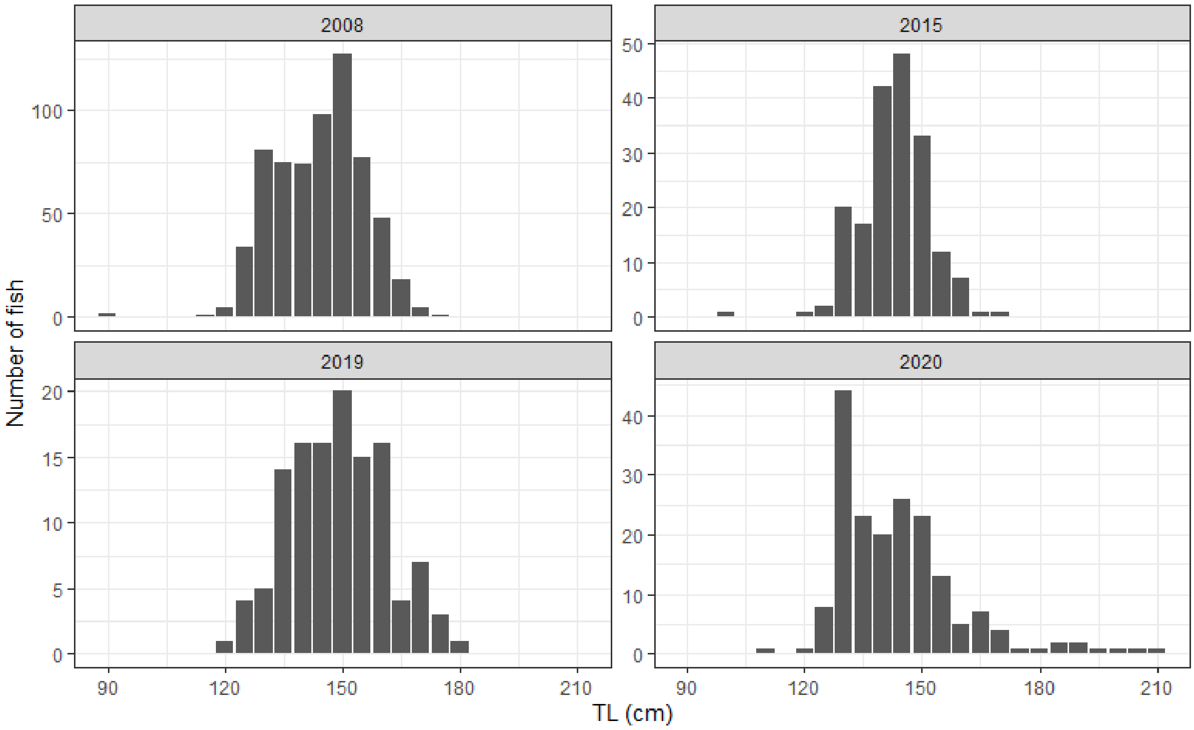

Figure 3. Vendace length frequencies distribution in the ringed seal diet in the reference years 2008, 2015, 2019 and 2020.

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Working document 7 – Vendace ensemble model

1.1. Ensemble Model

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1.1.1. Why use Ensemble model?

The main input parameters of a stock assessment are not often well known, ending up with a range of alternative scenarios for management, which should be scrutinized (Mannini et al, 2021). In this context, Hilborn and Walters (1992), when discussing which could be the best model to be used in assessing stocks, recalled an adage that "*the truth often lies at the intersection of competing lies*", this means deliberately comparing a range of alternative models.

The biggest novelty used in this benchmark assessment is that, instead of comparing outputs and selecting a single final model, ensemble modelling approach (Dietterich, 2000) was used to present results with a quantitative criterion for weighting several model predictions. Ensemble methods are promising approach when decision has to be made despite multiple and potentially conflicting estimates of stock status are present (Anderson et al. 2017). Ensemble models are proved to be more accurate and less biased than individual model teasing apart the conditions under which various model assumptions result in the most accurate predictions. Ensemble approach better encapsulates the variability and uncertainty exploring contrasting but plausible ranges of parameter values over choosing a single set of fixed values when the reliability of the single values is in question (Dietterich, 2000; Tebaldi & Knutti, 2009). This is crucial when the reliability of the single fixed parameters is in question. The goal is to quantify total uncertainty across models where the structural uncertainty is likely to be much greater than within model uncertainty. For example, ensembles are helpful because modellers need not decide on dome versus asymptotic fisheries selectivity (e.g. Sampson & Scott, 2012, FAO-GFCM, 2021), or on whether to fix or estimate natural mortality (e.g. Johnson et al., 2015).

1.1.2. Delta-MVLN estimator

To address structural uncertainties, the delta-Multivariate log-Normal (delta-MVLN) estimator (Walter and Winker, 2019; Winker et al., 2019) has been used here to generate and stich together the joint posterior distributions of plausible outcomes of target derived quantities (e.g. SSB/SSB_target and F/F_target). It infers within-model uncertainty from maximum likelihood estimates (MLEs), standard errors (SEs) and the correlation of the untransformed quantities and it has demonstrated to be able to mimic the Markov Chain Monte Carlo (MCMC) fairly closely (Winker et al., 2019). These quantities are derived by using the delta-method to calculate the asymptotic variance estimates from the inverted Hessian matrix of the Stock Synthesis model.

1.1.3. Parameters levels

Based on the importance of taking into account structural and parameters uncertainty, ensemble approach was selected as the best solution by the experts because represent all the possible "states of nature" of the stock under analysis based on a number of sources of natural and fisheries uncertainty. First level of uncertainty was linked to three alternative hypothesis of seals predation/consumption (see WD 6 – Ringed seal predation). Other alternative plausible hypotheses are based on three different levels of background natural mortality (M1; see WD 5 – Stock assessment of vendace in Bothnian Bay) and steepness (*h*). The final model grid for the ensemble included all combinations of alternative values for these three nested variables, as listed in Table XX1. Input files for each of the 27 runs can be found in the official SLU Aqua SharePoint.

Table XX1 - Parameters and levels employed in the final ensemble assessment grid for vendace in Bothnian Bay.

Parameter	Levels	Progressive number of runs	Values
Seals consumption	3	3	70% haul-out & low overlap (50%); 60% haul-out & mid overlap (60%); 50% haul-out & high overlap (70%);
Background mortality *(M1)*	3	9	Lower M1: 2020 Assessment; Medium M1: Average of Lower M1 & Upper M2; Upper M1: Estimated using t-max methods;
Steepness (*h*) in S-R	3	27	0.7;0.8;0.9

A schematic graphical representation of the assessment workflow is provided in Figure X1 to have a guideline for following the process behind the building of the runs grid created for the final ensemble.

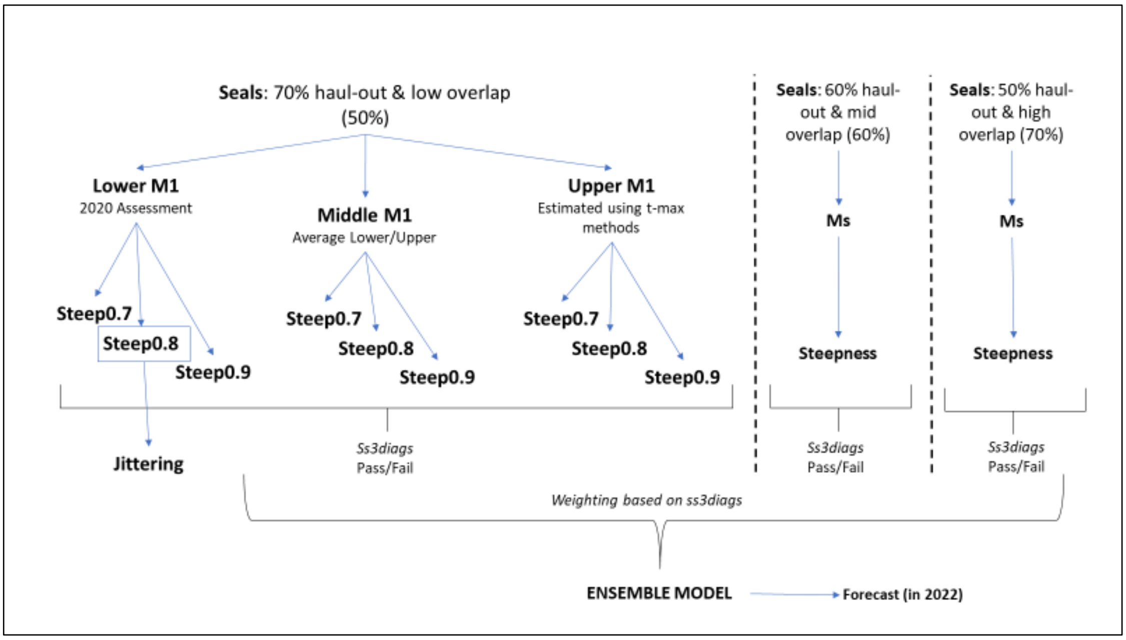

Figure X1 - Schematic graphical representation of the assessment workflow for vendace in Bothnian Bay.

1.1.4.Model weighting

The need to weight models based on information in the available data is recognized, but it is difficult to do so in a context in which the complexity of fisheries stocks assessment models prevents strict adherence with statistical rigor. In this context, the selected 27 grid runs represent the alternative states of nature of the stock and must be weighted in the final ensemble model. This is a necessary step because assigning the same weight (reliability) to all hypotheses could introduce biases into the management advice if some hypotheses are, in fact, highly unlikely. To assign weights to the various models and hypotheses, it is preferable to establish a system of discrete weight categories. In this benchmark assessment we decided to use diagnostic scores (*W(Diagnostics)*) as weighting metrics (Maunder et al., 2020), to judge the plausibility of each candidate model. In fact, when all diagnostic tests are considered together, the power to detect model misspecification improves without a substantial increase in the probability of incorrectly rejecting a correctly specified model (Carvalho et al., 2017). In this context, *W(Diagnostics)* component is calculated based on the series of interconnected diagnostic tests as discussed by Carvalho et al., 2021 and previously presented and explained for the reference run:

$$W(Diagnostics)\colon \frac{\boldsymbol{W}(\mathbf{Diags\ 1}) + \boldsymbol{W}(\mathbf{Diags\ 2}) + \boldsymbol{W}(\mathbf{Diags\ 3}) \ldots + \boldsymbol{W}(\mathbf{Diags\ N})}{\mathbf{Num\ of\ }\boldsymbol{W}(\mathbf{Diags})}$$

where to each W component a value of 1 is assigned when the run passed the diagnostic test and 0 when fail. Table XX2 summarize all main diagnostics for the 27 grid runs to be used as weighting metrics. Based on this result, different weighting was used to stich togheter the different runs in the final ensemble model. W(Diagnostics) value is used as a multiplicative factor of the number of simulations used by the delta-MVLN estimator (5000 in the case the W(Diagnostics) value is 100% and less accordingly to the value) when creating the derived quantities posterior distributions. The W(Diagnostics) threshold to keep any model configuration in the ensemble grid was fixed to 70%. In other words, if a model configuration has a W(Diagnostics) value less than 70% it will be excluded from the ensemble grid.

Table XX2 - Summary table of the diagnostics used in the weighting procedure. Green refers to “Passed” score.

	Convergence and stability		Goodness of the fit							Consistency				Prediction skills							
	Positive	Jittering	Run test					Joint-residuals		Retrospective analysis				Hindcasting (MASE)							
Run name	Hessian		CPUE	Survey	Len_Fleet	Len_Seals	Len_Survey	Index	Length	Retro_SSB	Forecast_SSB	Retro_F	Forecast_F	CPUE	Survey	Comb	Len_Fleet	Len_Seals	Len_Survey	Len_Comb	*W(Diagnostics)*
Run1	Passed		Passed	Passed	Passed	Passed	Passed	Failed	Passed	Passed	Failed	Passed	Failed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	**0.78**
Run2	Passed		Passed	Passed	Passed	Passed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	**0.94**
Run3	Passed		Passed	Passed	Passed	Passed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	**0.94**
Run4	Passed		Passed	Passed	Passed	Passed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	**0.94**
Run5	Passed		Passed	Passed	Passed	Passed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	**0.94**
Run6	Passed		Passed	Passed	Passed	Passed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	**0.94**
Run7	Passed		Passed	Passed	Passed	Failed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	**0.89**
Run8	Passed		Passed	Passed	Passed	Passed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	**0.94**
Run9	Passed		Passed	Passed	Passed	Passed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	**0.94**
Run10	Passed		Passed	Passed	Passed	Passed	Passed	Failed	Passed	Passed	Failed	Passed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	**0.83**
Run11	Passed		Passed	Passed	Passed	Passed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	**0.94**
Run12	Passed		Passed	Passed	Passed	Passed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	**0.94**
Run13	Passed		Passed	Passed	Passed	Failed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	**0.89**
Run14	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	**0.94**
Run15	Passed		Passed	Passed	Passed	Passed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	**0.94**
Run16	Passed		Passed	Passed	Passed	Passed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	**0.94**
Run17	Passed		Passed	Passed	Passed	Passed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	**0.94**
Run18	Passed		Passed	Passed	Passed	Passed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	**0.94**
Run19	Passed		Failed	Passed	Passed	Passed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Failed	Passed	Failed	Passed	Passed	Passed	Passed	**0.78**
Run20	Passed		Passed	Passed	Passed	Passed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	**0.94**
Run21	Passed		Passed	Passed	Passed	Passed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	**0.94**
Run22	Passed		Passed	Passed	Passed	Passed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	**0.89**
Run23	Passed		Passed	Passed	Passed	Passed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	**0.94**
Run24	Passed		Passed	Passed	Passed	Passed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	**0.94**
Run25	Passed		Passed	Passed	Passed	Failed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	**0.94**
Run26	Passed		Passed	Passed	Passed	Passed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	**0.94**
Run27	Passed		Passed	Passed	Passed	Passed	Passed	Failed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	**0.94**

1.1.5. Model results

To recap, to capture structural uncertainties, a range of alternative models was selected through diagnostics (interconnected diagnostic tests; Carvalho et al. 2021, Maunder et al. 2020, Kell et al., 2021), to be stitched together using delta-Multivariate log-Normal estimator (delta-MVLN; Walter and Winker 2019; Winker et al. 2019). Below is reported the table (Table XX3) with all run specification and final weighting factor used in the ensemble procedure. All configurations passed the 70% threshold with only two runs having a score of 0.78 (run1 and run19). The final outputs from the ensemble model are based on the weighted-median value of the 27 runs.

Name	Seals	Natural Mortality	Steepness	Weighting
run1	low	M1 low	0.7	**0.78**
run2	low	M1 middle	0.7	**0.94**
run3	low	M1 high	0.7	**0.94**
run4	low	M1 low	0.8	**0.94**
run5	low	M1 middle	0.8	**0.94**
run6	low	M1 high	0.8	**0.94**
run7	low	M1 low	0.9	**0.89**
run8	low	M1 middle	0.9	**0.94**
run9	low	M1 high	0.9	**0.94**
run10	middle	M1 low	0.7	**0.83**
run11	middle	M1 middle	0.7	**0.94**
run12	middle	M1 high	0.7	**0.94**
run13*	**middle**	**M1 low**	**0.8**	**0.89**
run14	middle	M1 middle	0.8	**0.94**
run15	middle	M1 high	0.8	**0.94**
run16	middle	M1 low	0.9	**0.94**
run17	middle	M1 middle	0.9	**0.94**
run18	middle	M1 high	0.9	**0.94**
run19	high	M1 low	0.7	**0.78**
run20	high	M1 middle	0.7	**0.94**
run21	high	M1 high	0.7	**0.94**
run22	high	M1 low	0.8	**0.89**
run23	high	M1 middle	0.8	**0.94**
run24	high	M1 high	0.8	**0.94**
run25	high	M1 low	0.9	**0.94**
run26	high	M1 middle	0.9	**0.94**
run27	high	M1 high	0.9	**0.94**

**Reference run described in details in the previous chapter (WD 5)*

The ensemble model based on 27 model runs proposed during the benchmark (Table XX3) has been considered as the final model for providing scientific advice. Figures X2 presents the main outputs from the final ensemble model compared with the single runs:

- <u>State of the adult biomass (*SBB*):</u> Total spawning biomass of vendace follows a fluctuating trend. In the last 20 years there have been two 2 peaks (2005 and 2015) associated with extremely favorable recruitment event occurred in previous years (lag of about 2 years between peak in Recr and SSB). The last estimate of *SSB* in 2020 is 6964 tons (CI: 3711 - 14660).

- <u>State of exploitation (*F*):</u> Fishing mortality is defined as the average *F* of age classes 1 to 3. Historical *F* shows the great variability due to the relatively small amount of information (only total catches) for that part of the time series. Since 1995 F stabilizes, always remaining at rather low levels. The last estimate of *F* in 2020 is 0.09 (CI: 0.04 - 0.16)

- <u>State of the juveniles (*Recr*):</u> Recruitment up to 2000 is quite constant as data informing recruits estimates are only available since 1997 (first year of commercial LFDs). Since then, recruitment has shown a fluctuating trend with extreme peak in 2013; in the last year estimate recruits are 300242 (CI: 96047 - 996929)

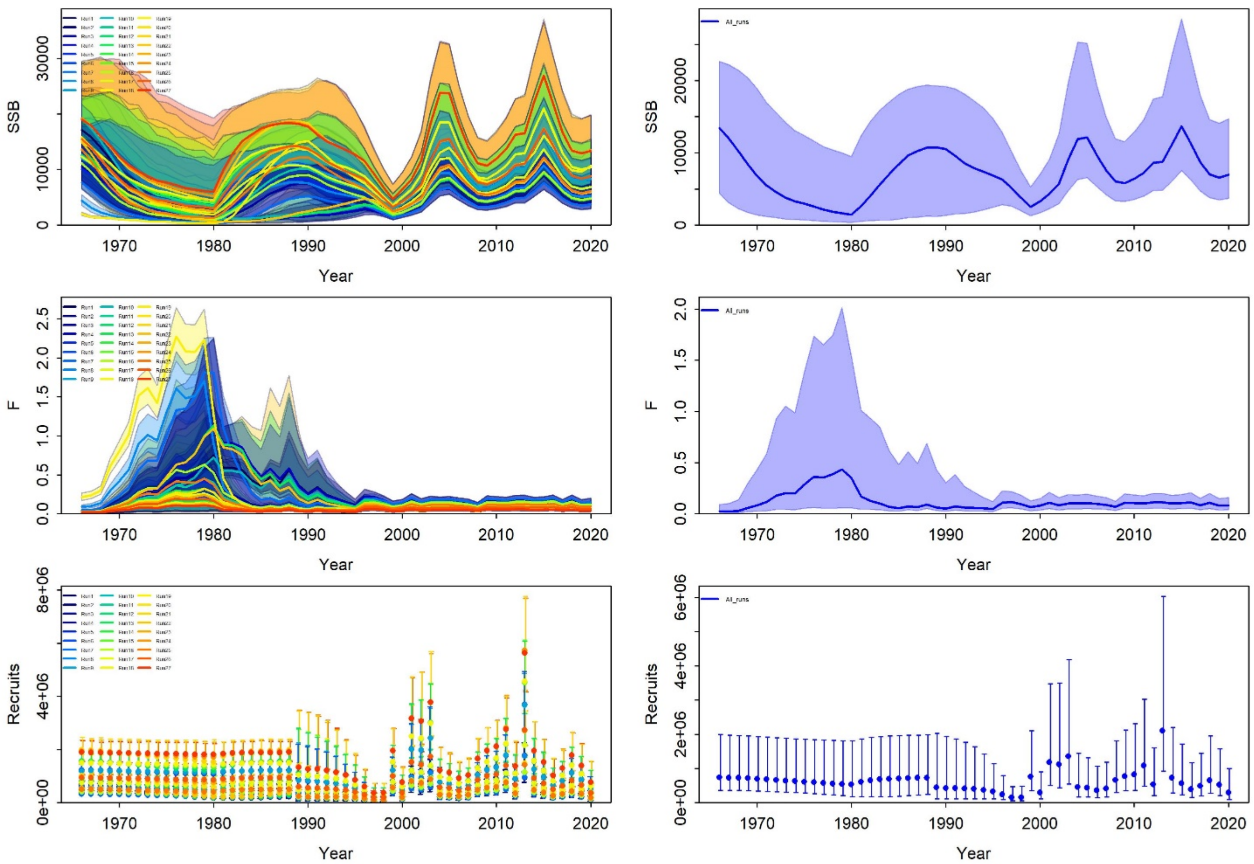

Figure X2 – Comparison of stock assessment result between the 27 single runs (3 panels on the left) and the final ensemble model (3 panels on the right). Weighted-median value of SSB, F and Recr with 95% confidence intervals from delta-MVLN.

Figure X3 shows the trajectory of the stock over the reference points (chosen as described in the dedicated chapter). In the current year (2020) the stock is considered to be in a good status since spawning stock biomass is estimated to be above the reference point (*SSB/SBBtrg* = 1.55; CI: 1-2.11), and fishing mortality is estimated to be below the reference value (*F/Ftrg* = 0.18; CI: 0.07 - 0.42).

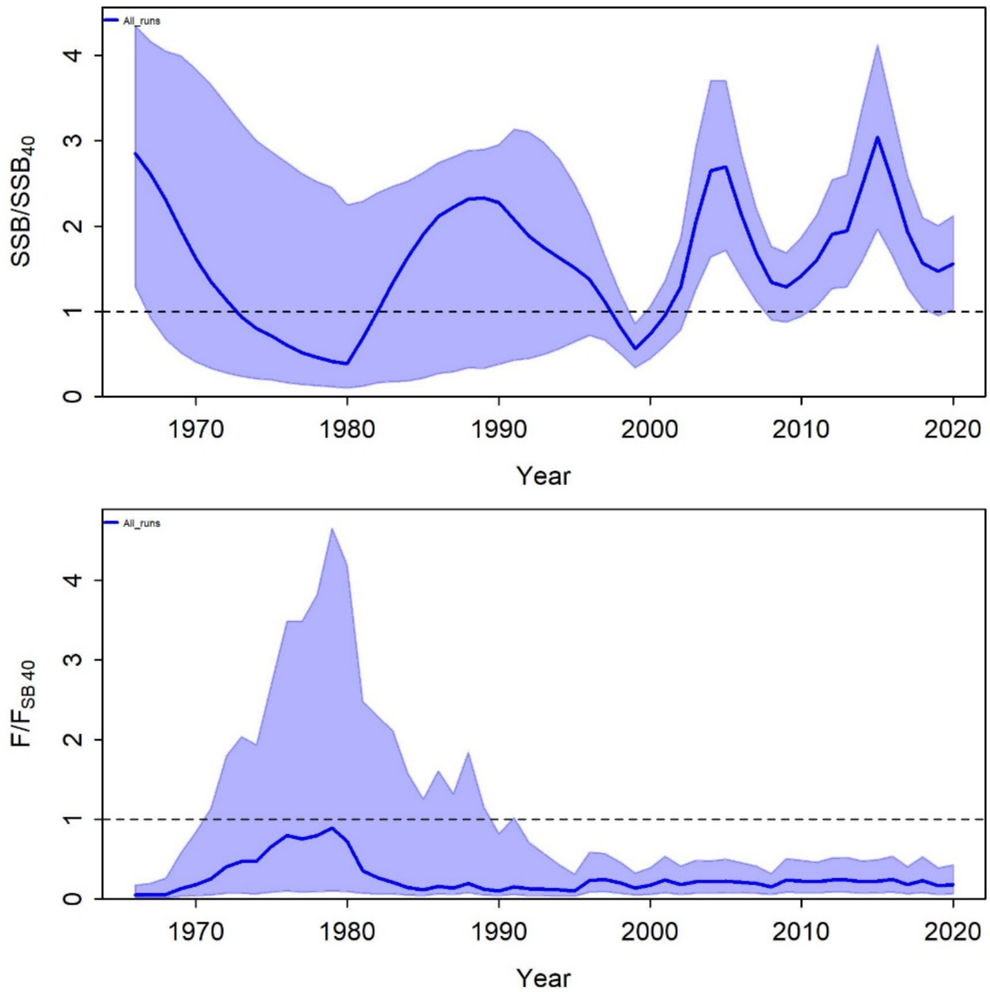

Figure X3 - Stock status trajectories based on SS3 final ensemble model (weighted-median value of 27 runs). SSB/SSB40 (upper panel) and F/F40 (bottom panel) time series with 95% confidence intervals from MVLN.

Figure X4 represent the Kobe plot for the ensemble model. Kobe plot represents the time series of pressure (*F/Ftarget*) on the Y-axis and of state of the Biomass (*SSB/SSBtarget*) on the X-axis. The orange area indicates healthy stock sizes that are about to be depleted by overfishing. The red area indicates ongoing overfishing while the stock is too small to produce maximum sustainable yields. The yellow area indicates reduced fishing pressure on stocks recovering from still too small biomass. The green area is the target area for management, indicating sustainable fishing pressure and healthy stock size capable of producing high yields close to the reference point chosen (MSY or proxies).
Stock trajectory begun in 1965 in the green quadrant, when the biomass was quite higher compared to the reference point. In the period 1975 - 1980, the *F* level registered an increasing trend that resulted in a progressive erosion of the stock size which led the stock trajectory towards the yellow quadrant. From the moment when *F* returned to decline and stabilize over the years, it was only around the 2000s that the stock returned to the yellow zone. After 2000s, the stock has always remained in the green quadrant of the plot. In 2020 there is about 96% probability that the stock is in the green quadrant of the Kobe plot (i.e. *SSB* > *SSB40* and *F* < *F40*) with low probabilities of about 4% to be in the yellow (i.e. *SSB* < *SSB40* and *F* < *F40*) and zero to be in the red (*SSB* < *SSB40* and *F* > *F40*).

In conclusion, the stock is considered to be in a good status both from a biomass and a fishing mortality point of view at the current level of mortality exerted by the seals.

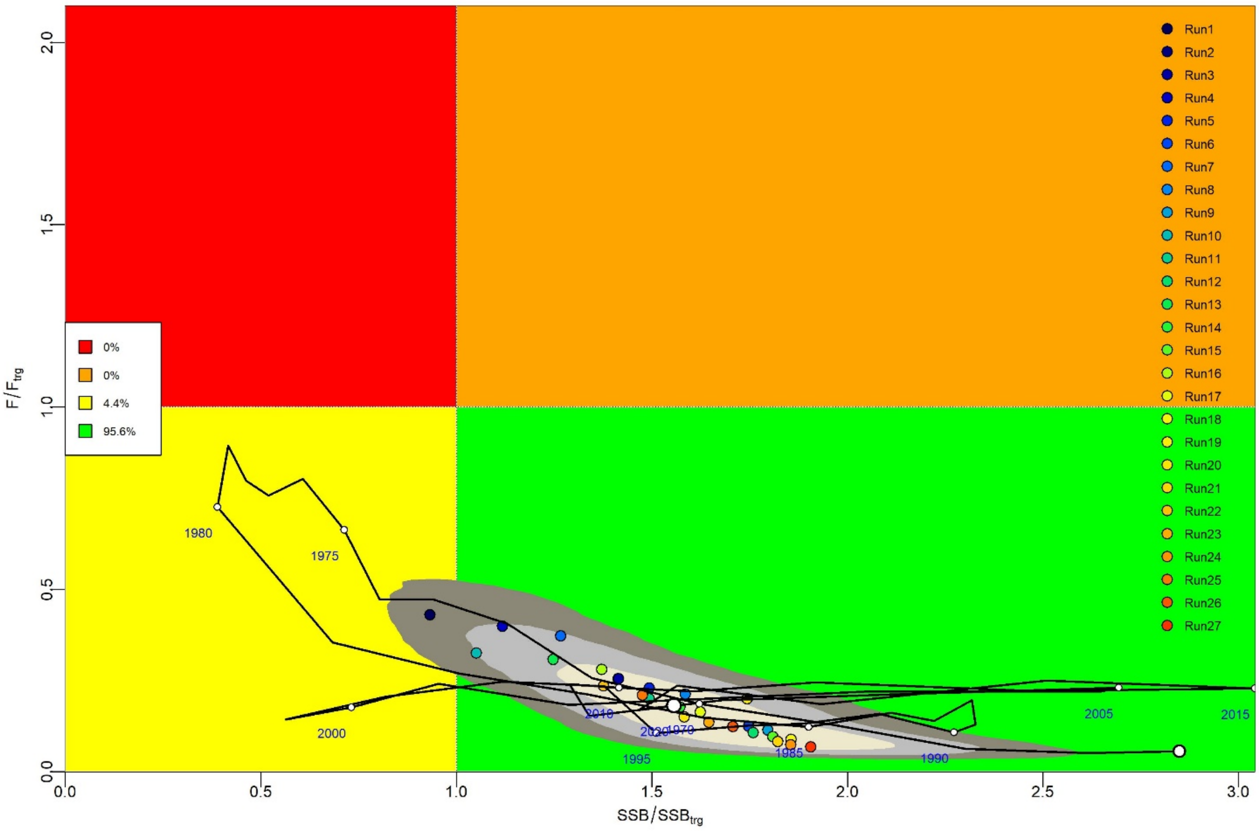

Figure X4 - Kobe plot showing the trajectory of relative stock size (SSB/SSB40) over relative exploitation (F/F40) based on SS3 final ensemble model (white dot: weighted-median value of 27 runs). Gray shading indicates CI of 50%, 80% and 95% from delta-MVNL of the final assessment year (2020). The legend indicates the estimated probability of the stock status being in each of the Kobe quadrant.

Figure X5 shows the results of the ensemble model in the form of a kobe-plot by grouping the different runs by key parameters levels. Looking at the three plots, it appears clear that the background natural mortality *M1* has major impact on model results (Fig X5, b). Second for impact, the predation of seals (Fig X5, a) which is linked to the natural mortality as it is directly used by the model to estimate predation mortality *M2* (*M1* + *M2* = *M*). These results are reasonable given that *M* is considered one of the most influential parameters on the final result of a stock assessment (Mannini et al, 2021). The parameter that seems to have a minor influence on the results is the steepness used in stock recruitment relationship (Fig X5, c).

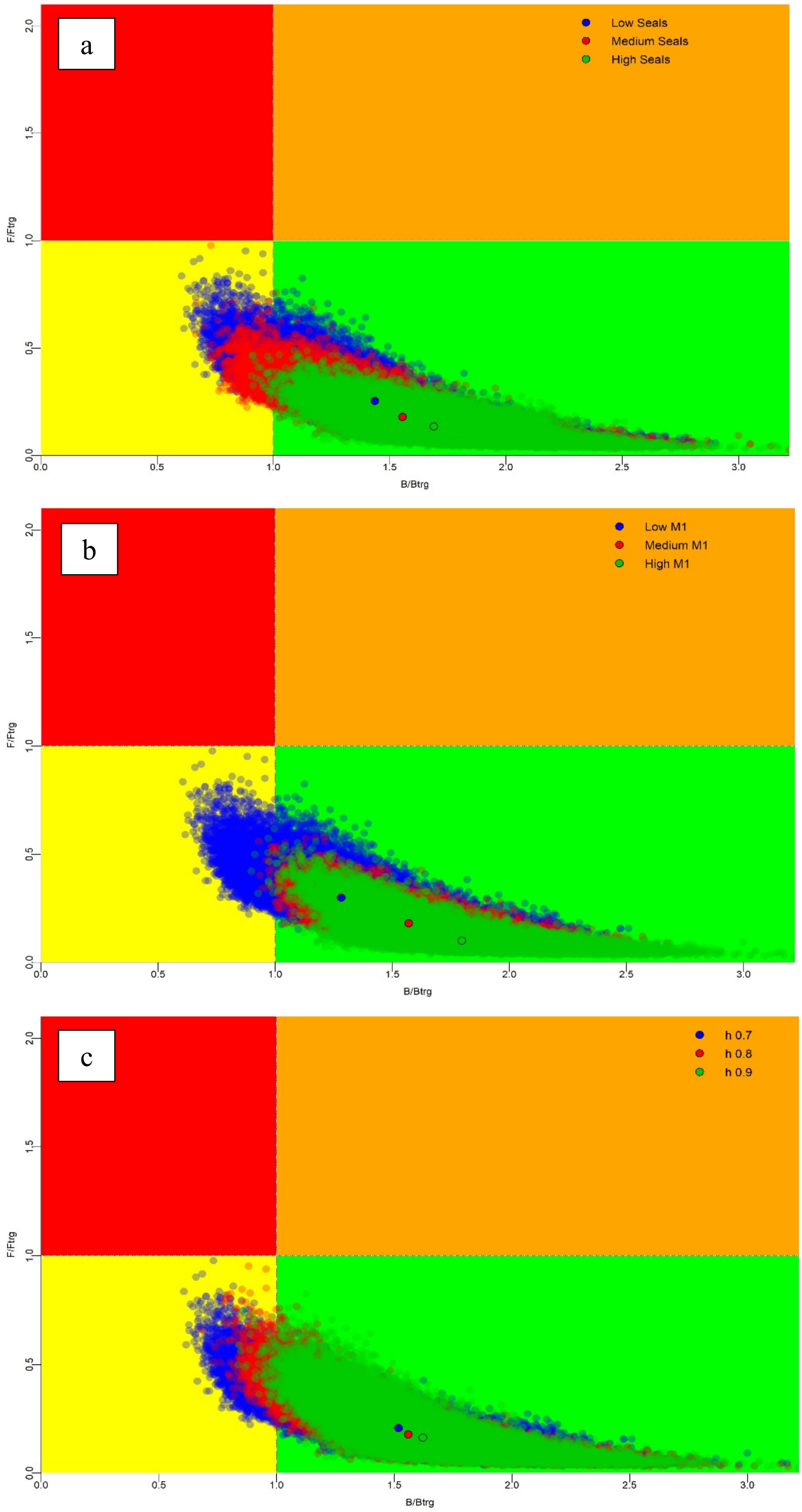

Figure X5 – Kobe plots showing the relative stock size (SSB/SSBtarget) over relative exploitation (F/Ftarget) by grouping the different runs by key parameters levels (9 runs per level, weighted-median values by level are showed). a) Seals predation; b) Background natural mortality; c) Steepnees (h).

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WD 8: Management strategy evaluations (MSE) of vendace in the Bothnian Bay

By Massimiliano Cardinale

Summary

MSE (Management Strategy Evaluations) were used to determine the target and trigger reference points to be used to provide advice for vendace in the Bothnian Bay. Reference points were expressed in relative terms (relative to a fraction of B_0) and corresponds to $F_{B40\%}$ with $B_{trigger}$ set at 1.0 of $B_{40\%}$ This allows the highest long term yield conditional to a long-term low probability (i.e., less than 5%) of the SSB to fall below B_{lim} (set as 15% of B_0). In addition, the MSE shows that a deterministic F_{MSY} is not precautionary as it has a larger probability (P=0.26) to bring the stock below B_{lim}, and the difference in long term yield between the MSE approach and fishing at the determinist F_{MSY} is less than 9%, with a long term SSB that is on average 67% larger than B_{MSY}.

Methods

To conduct the MSE, we used the simulation-testing framework available in the Fisheries Library for R (FLR; Kell et al., 2007; https://flr-project.org/). The simulation framework was implemented in the FLR library `mse` (https://github.com/flr/mse) with `FLasher` (https://github.com/flr/FLasher). Reference points at equilibrium were calculated with the library `FLBRP` (https://github.com/flr/FLSRTMB). To facilitate customized reference point estimation and visualisation of F_{MSY} proxy (hereafter defined as F_{brp}, which in this case was expressed as the F that brings the stock at a given fraction of B_0, i.e. $F_{B\%}$; see the Glossary at the end of the document for the definition of reference points), B_{lim}, $F_{P.05}$, B_{trg}, F_{trg}, we used the FLR package `FLRef` (https://github.com/henning-winker/FLRef). `FLRef` makes use of the new fast forward projection 'ffwd()` in `FLasher` together with the bisection function `bisect()` in 'mse' to efficiently derive precise values of $F_{P0.5}$ based stochastic simulations. The R code used in this analysis is available in the SLU SharePoint of vendace benchmark (https://arbetsplats.slu.se/sites/aqua/Projekt/vendace/SitePages/Home.aspx).

The simulations were run for the 27 models included in the ensemble (hereafter defined as R1 to R27, see WDxx for a description of the models). The operating models were implemented as single sex and single fleet models with an annual time step. Future projections were run over 60 years (i.e., 2021-2080) with 250 iterations and based on the 3-years average of the most recent data years for weight-at-age, maturity-at-age, natural mortality-at-age and the F pattern determining the selectivity-at-age. This choice was made to account for non-stationary (i.e., time varying) processes in these quantities and reflects the most recent biological and exploitation history of the stock. The performance evaluations were based on the last 10 years of the 60-year projection horizon (i.e., 2071-2080). For the simulation testing, stock and recruitment, steepness, sigma R and autocorrelation were set as equal to the one estimated for each model of the ensemble. The recruitment deviation is assumed to be associated with a first-order autocorrelation (AR1) process and a function of recruitment standard deviation σ and the AR1 coefficient ρ (Johnson et al., 2016) which are both estimated within the model. Simulations included implementation error, representing the deviations between the observed and advised catches. As only three years of TAC exists for the vendace fishery in the Bothnian Bay, an average value of 0.05 and 0.15 standard deviation was assumed.

Harvest control rules (HCRs) are kept generic and in the same form of the conventional ICES Advice Rule (ICES, 2021a), where the advice decreases from F_{trg} to zero as SSB decreases from $B_{trigger}$ to zero. Variations in performances of the tested HCRs are therefore determined by the parameters F_{trg} and $B_{trigger}$. The HCRs were implemented using a simulated feedback control loop between the implementation system and the operating model (OM), where the implementation system translates the assessment outcome via the HCR into the Total Allowable Catch (TAC) advice (Figure 1). The key difference to a simple stochastic risk simulation, the EQsim model used for reference points calculations by ICES (ICES 2021), is that the simulated feedback control loop between the implementation system and the operative model (OM), allows accounting for the lag between the last year of data used in the assessment and the implementation year of the TAC advice. In ICES, the implementation system of the harvest control rule assumes that advice is given for year y+1 based on an assessment completed in year y, which is typically fitted to data up until year y-1 (ICES, 2020). Therefore, implementation of the TAC derived through HCR requires projection of the stock dynamics by way of a short-term forecast (Mildenberger et al., 2021). In contrast to a full Management Strategy Evaluation (MSE) simulation design (Punt et al., 2014), this MSE ‘short-cut’ approach (e.g., ICES, 2020), omits the step of the annual updating of the estimation model (assessment) in the feedback control. Instead, it passes the 'true' age-structured dynamics from the OM to the HCR implementation. The merits of a short-cut MSE approach include the incorporation of the lag effect between data, assessment and management implementation. The limitations of the MSE short-cut approach are that it cannot fully account for uncertainties resulting from imperfect sampling of the full age-structure (e.g. poorly sampled recruits), observation error and model estimation error.

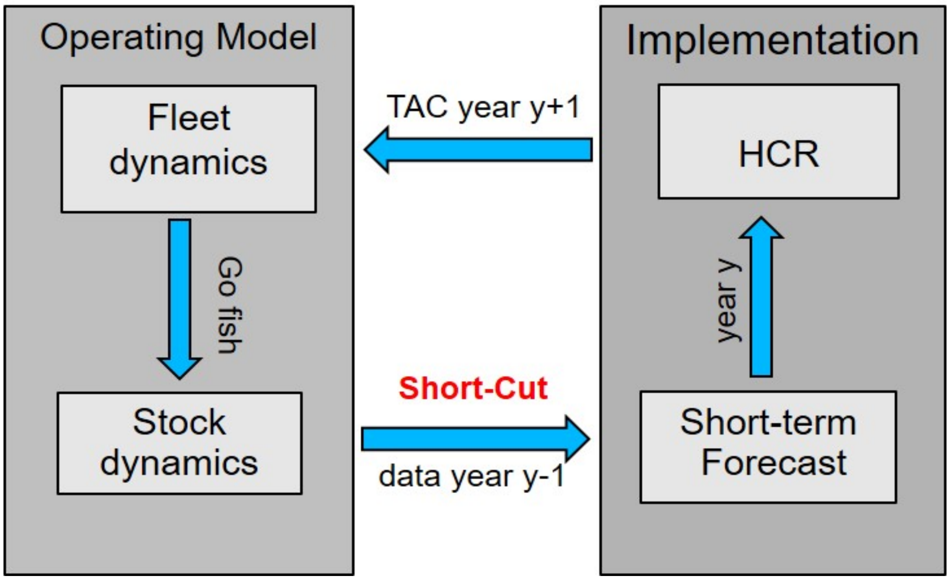

Figure 1. Schematic illustrating the key processes of the short-cut approach to MSE, showing the Operating model that simulates the fishery and stock dynamics on the left and Implementation System including the short-term forecast on the right. The short-cut denotes the omission of the estimation (stock assessment) model that updates to new observations (with estimation error) in a conventional MSE implementations with full feedback control loop.

Performance Evaluation Criteria

The consistency tests were designed to identify the generic rules for specifying F_{brp}, B_{trg} and $B_{trigger}$ according to stock-specific productivity that provide the optimal trade-offs among the following two main objectives: (1) to not exceed a 5% probability of SSB falling below B_{lim} in any single year, and (2) to achieve the highest possible long-term yields given condition (1). Consistent with the objectives of the ICES advice framework (ICES, 2020), the two objectives are interpreted hierarchically in that objective (1) is the overriding criteria of maintaining stock size above B_{lim} with at least 95% probability, to be compliant with the ICES Precautionary Approach (PA). Conditional on objective (1), objective (2) is based on the ICES definition for using plausible values around F_{target} in the advice rule, which are derived so that they lead to minimum possible reduction from the MSY obtained by fishing at the deterministic F_{MSY} in the long term.

In the previous assessments (Bergenius et al., 2021), the lowest observed SSB that was able to produce at least one average recruitment was used to derive B_{lim}. In ensemble models, B_{loss} will be inherently different for the different model configurations and therefore fractions of B_{MSY} or B_0 are used (ICES, 2022). Here we have chosen to define B_{lim} as a fraction of B_0, which compared to B_{MSY} has the advantage to be independent to selectivity. When expressed as a fraction of B_0, those generally ranges from 0.1 to 0.2 B_0 (ICES, 2022). For vendace, B_{lim} was set at 15% of B_0. This was done because, as shown by WKREF1, setting B_{lim} below 10% of B_0 renders $F_{P.05}$ ineffective for most ICES stocks with or without the use of $B_{trigger}$ (ICES, 2022). In addition, the Allee effect (i.e., depensation) in exploited fish has been estimated to occur when the stock is below 15-25% of B_0 (Perälä and Kuparinen, 2017; Perälä et al., 2021) and therefore 15% of B_0 was chosen as representing the lower limit in SSB where depensative mechanisms might start to arise.

Blim definierades 2019 som den lekbiomassa som producerade minst en genomsnittlig mängd ungfisk, men under vilken mängd lekbiomassa som tidserien visar att ungfiskproduktionen har minskat.

Results

15 scenarios (i.e., 5 x $F_{B\%}$ time 3 x $B_{trigger}$ and the deterministic F_{MSY} were tested for the 27 models of the ensemble to assure enough contrasts between the different scenarios. The SR relationship for the different models of the ensemble is shown in Figure 2. As an example of the realised simulations, trends in SSB, F, landings and R for the different combinations of F_{target} and $B_{trigger}$, compared to the deterministic F_{MSY} are shown for R13 (Figure 3).

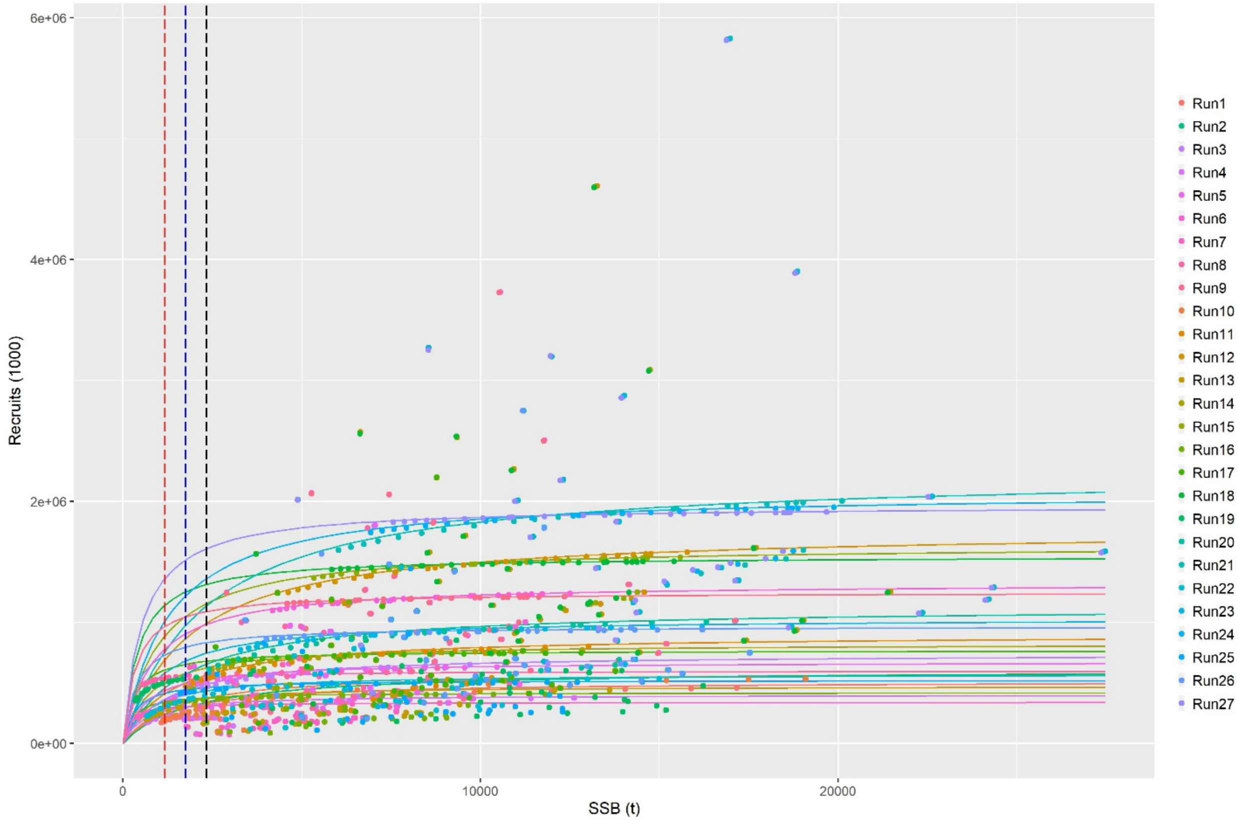

Figure 2. Stock-Recruitment relationship for the 27 models of the ensemble. Red, blue and black line are median $B_{10\%}$, $B_{15\%}$ and $B_{20\%}$ for the 27 models.

The results of the MSE showed that $F_{B40\%}$ with $B_{trigger}$ set at 1.0 of $B_{40\%}$ achieved the highest long term yield contingent to a median probability of SSB to fall below B_{lim} which is less than 5% (Figure 4). Fishing at F_{MSY} is not precautionary as it implies a median probability of SSB to fall below B_{lim} larger than 25.6% with extreme values up to 40%. The difference in long term yield between $F_{B40\%}$ with $B_{trigger}$ set at 1.0 and fishing at the determinist F_{MSY} is less than 9% with a long term SSB that is on average 67% larger than B_{MSY}.

Candidate	P3(B<Blim)	Catch/MSY	B/BMSY
fb40.bt06	0.068	0.94	1.52
fb40.bt08	0.052	0.92	1.59
fb40.bt1	0.040	0.91	1.67

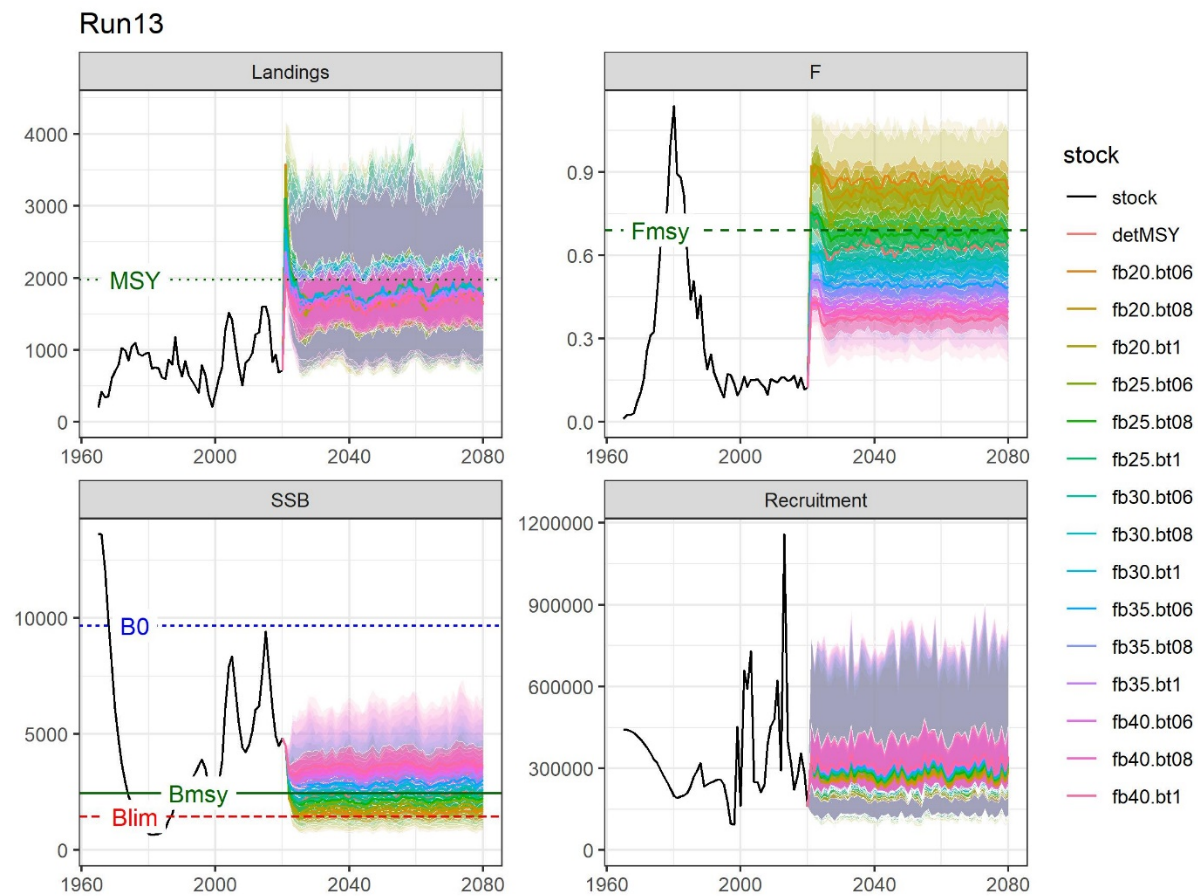

Figure 3. Long term simulations for Run13. Trends in SSB, F, landings and R for different combinations of F_{target} (fb) and $B_{trigger}$ (bt) and compared to the deterministic F_{MSY} (detMSY).

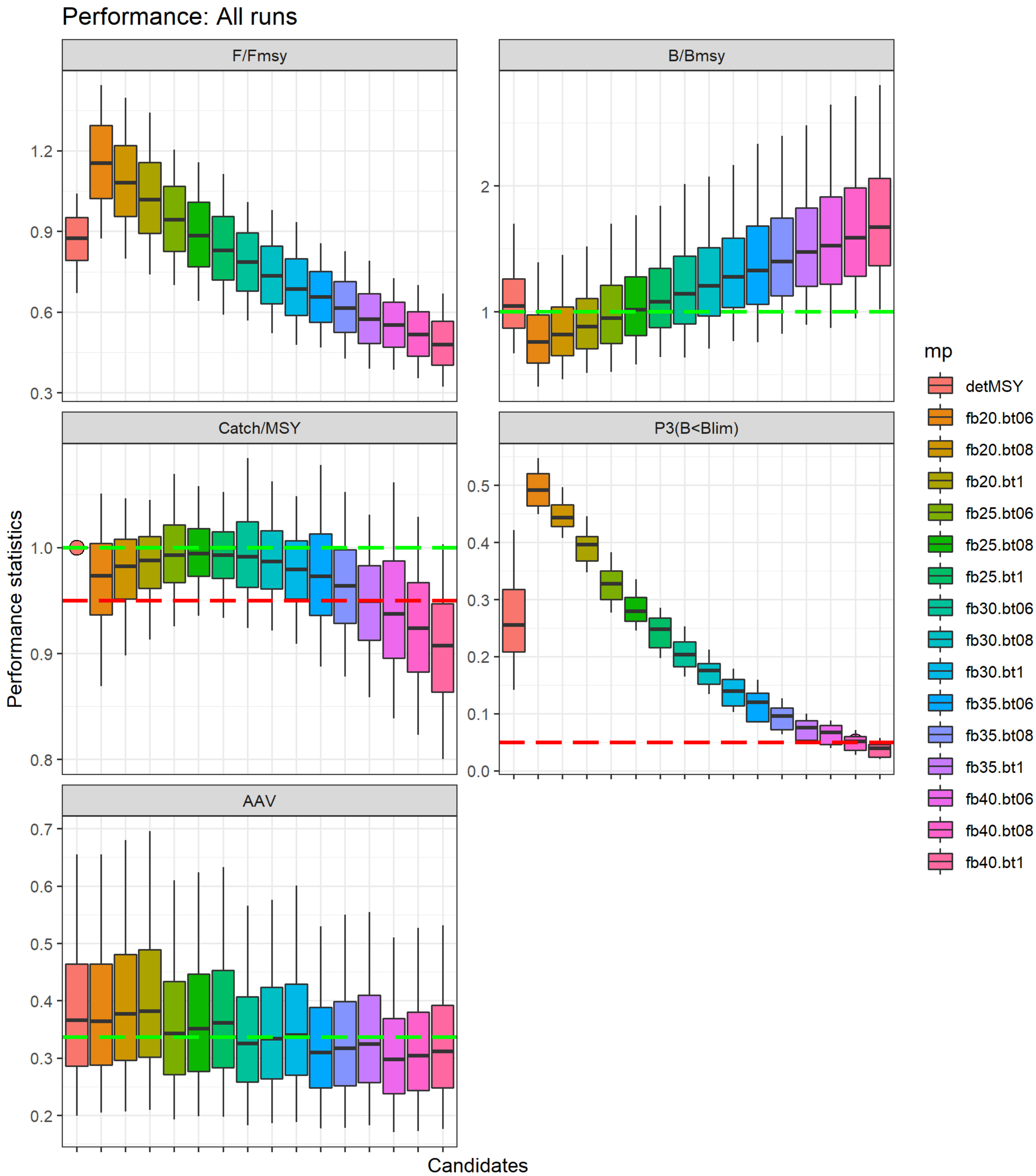

Figure 4. Results of MSE used of evaluate reference point systems, showing the type 3 risk probabilities (P3) of SSB falling below B_{lim}, the median long-term yield (Catch) relative the median long term obtained at fixed deterministic F_{MSY} (MSY), the median long term F and SSB relative to the deterministic F_{MSY} and B_{MSY} and the median long term interannual variation in catches (AAV). Green and red dashed lines denote the target and limit thresholds, respectively. Candidates based on $F_{B\%}$ and $B_{trigger}$ as fraction of $B_{\%}$, where, e.g., fb40.bt1 denotes $F_{B40\%}$ with $B_{trigger}$ set at 1.0 of $B_{40\%}$.

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Glossary

B_{lim}: A deterministic biomass limit below which a stock is considered to have reduced reproductive capacity. For stocks where quantitative information is available, a reference point B_{lim} may be identified as the stock size below which there is a high risk of reduced recruitment.

B_{loss}: It is the lowest observed SSB in the assessment time series and commonly used as a proxy for B_{lim} (i.e. Type 5 within the current ICES advice framework).

B_{pa}: A precautionary safety margin incorporating the uncertainty in ICES stock estimates leads to a precautionary reference point B_{pa}, which is a biomass reference point designed to have a low probability of being below B_{lim}. When the spawning-stock size is estimated to be above B_{pa}, the probability of impaired recruitment is expected to be low. B_{pa} is estimated as a function of B_{lim}.

F_{lim}: The fishing mortality which in the long term will result in an average stock size at B_{lim}. Fishing at levels above F_{lim} will result in a decline in the stock to levels below B_{lim}.

$F_{P.05}$: The fishing mortality that results in no more than 5% probability of bringing the spawning stock to below B_{lim} in the long term.

F_{pa}: Same as $F_{P.05}$

F_{MMY}: The maximum medium yield F_{MMY} denotes the fishing mortality that corresponds to the peak of the median landings yield curve derived from stochastic forward projections as is typically derived from the EQSIM software (i.e. "FMSYmedianL"). Within the ICES advice framework, the quantity F_{MMY} is typically referred to as F_{MSY}. However, for FMMY to directly translate into FMSY as reported on the advice sheet, F_{MMY} first requires meeting the condition that $F_{MMY} < F_{P0.05}$ in accordance with precautionary principle. For the purpose of this report a clearer definition was therefore needed to separate the initial estimate of F_{MSY}, here F_{MMY}, from the final advice for F_{MSY}.

F_{MSY}: Within the ICES advice framework F_{MSY} is specified as $F_{MSY} = \mathit{min}(F_{P.05}, F_{MMY})$. Within an international or operating model (simulation) context, F_{MSY} is referred to as a biological reference point that specifies the fishing mortality rate that, if applied constantly, would result in an average catch corresponding to the Maximum Sustainable Yield (MSY) and an average biomass corresponding to B_{MSY}.

MSY $B_{trigger}$: MSY $B_{trigger}$ is the parameter in ICES MSY framework which triggers advice on reducing fishing mortality relative to F_{MSY}. MSY $B_{trigger}$ is considered the lower bound of SSB fluctuation (fifth percentile of the B_{MSY} estimate) when fished at F_{MSY}, but is set for a large majority of stocks equal to B_{pa}.

$B_{trigger}$: Generalization of the MSY $B_{trigger}$, which can differ in the way it is specified.

B_{MSY}: It is the expected average biomass if the stock is exploited at F_{MSY}, but currently not reported in ICES.

B_0: In age-structured models, B0 is the unfished spawning biomass that is given by the product of virgin recruitment R_0 (implicit to the stock recruitment relationship) and the unfished spawning biomass-per-recruit (SPR_0) being a function of weight-at-age, maturity-at-age and natural mortality. Like

B_{MSY}, it is therefore an implicit property of any age-structured model for which a SRR is estimated or assumed, but currently not reported in ICES.

$SB_{\%}$: The percentage spawning stock biomass of the unfished B_0 (e.g. B_{40})

MSY Proxies: Analytical proxies for B_{MSY}, F_{MSY} and MSY are quantitative surrogates that can be used if direct estimation is not possible or the estimates are not considered reliable.

F_{max}: The fishing mortality at which the yield-per-recruit is maximized. F_{max} remains relevant to the ICES advice rule in many cases where segmented regression is assumed for stock recruitment relationship, because F_{MMY} as the direct estimate of F_{MSY} is the same as F_{max} on a yield-per-recruit curve for the range of SBB > B_{lim}.

$F_{0.1}$: The fishing mortality at which the slope of the yield-per-recruit curve is 10% of that at the origin

$F_{spr\%}$: The fishing mortality at which the spawner-biomass-per-recruit (SPR) is, e.g. 40%, of its unexploited level SPR_0 (a common range is F_{spr30} -F_{spr50}).

$F_{B\%}$: The fishing mortality at which the spawning stock biomass (SSB) is e.g. 40% of its unexploited level at B_0, i.e. F_{B40}

F_{brp}: Biological referent point proxy of F_{MSY} (e.g. $F_{spr\%\ and}$ $F_{B\%}$)

WD 9: Genetics of vendace in the Bothnian Bay – preliminary results.

The stock structure of Vendace in the Bothnian Bay based on genetics

Mikaela Bergenius Nord, Maria Lopez, Anti Vasemägi, Olavi Kaljuste, Zeynep Hekim.

This WD is in an early DRAFT form of a publication in preparation and just intended to give the participants of the benchmark of vendace in the Bothnian Bay an indication of the results from the genetics analyses. The material should therefore in its current form be classified as working material.

Introduction

The aim of this study was to investigate the population structure of vendace (*Coregonus albula*) in the Northern Baltic Sea. Stock identification is a prerequisite for sound stock assessment and fishery management. The closer a management unit reflects the biological structure of the population, the more likely it is to achieve long-term sustainable harvests and populations. Currently, vendace on the Swedish side of the Bothnian Bay area (SD 31) is managed as one population, and vendace off the coast of Finland, as one population. However, the structure of the vendace population in the Bothnian Bay is not well understood. A tagging study conducted in the Luleå and Kalix archipelagos in the 1960s and 1970s show that vendace undertake natal homing, i.e. the adults return to their birthplace archipelago to reproduce (Enderlein 1977, 1986). The study also shows that vendace during summer migrates eastwards to more nutritious waters during which sub-populations or stocks from different fjords mixes (Enderlein 1986). Although the number of returns were few, some individuals were found to move all the way east to the Finnish coast. Thus, the question becomes to what degree there different sub-populations or stocks of vendace are genetically distinct and thus require separate, or a meta-population type management (REF). The specific aims of this project is therefore to identify 1) if vendace off the Swedish and Finnish coasts in SD 31 belong to the same population, 2) if the vendace population on the Swedish coast are composed of one or several sub-populations or stocks. We are well aware that for the appropriate management of any fish population the consideration of the proportion of each component in the fisheries catch from a mixture of sub-populations is the important next step after the identification of the genetic differentiations between the components. In this study, we focused on step one and sampled spawning fish in several locations. In the discussion we outline the appropriate process for step two.

Methods

Sampling (Olavi and Zeynep expand this section)

Vendace were sampled from spawning grounds of the Bothnian Bay during spawning time in autumn 2019 and 2020. In 2019 the samples were collected from passive gears (gillnets and trapnets) in mid-October (weeks 41-42) to guarantee the catch of local spawning fish. Samples were collected from 4 sites in total; 2 sites located in mouths of Piteå and Kalix rivers (marked as 1 and 6) and 2 sites in the coastal area off Piteå and Kalix (marked as 2 and 5 in Figure 1). In 2020 two additional vendace genetic samples were collected from survey trawl catches in mid-October (week 42). These 2 sites were in the coastal area off Piteå and Luleå (marked as 3 and 4 in Figure 1). Vendace were also sampled from two locations off Uleåborg in Finland in 2020 (marked as 7 and 8 in Figure 1). Samples were taken from the trawled catch in the harbour during spawning season (October and November, weeks 41 and 49).

From each site, 50 ripe individuals with running roe or sperm were randomly collected and frozen immediately. In the laboratory individuals were thawed and a small piece of the muscle tissue (ca 0.5 cm^3) taken as soon as possible to ensure minimum degradation of the DNA in the sample. The small piece of muscle tissue was taken using a clean scalpel (by rinsing the scalpel in water between samples and wiping it clean with paper towel) and stored in 95% ethanol. All individuals were sampled for biological parameters length, weight, gender, maturity status and age determination.

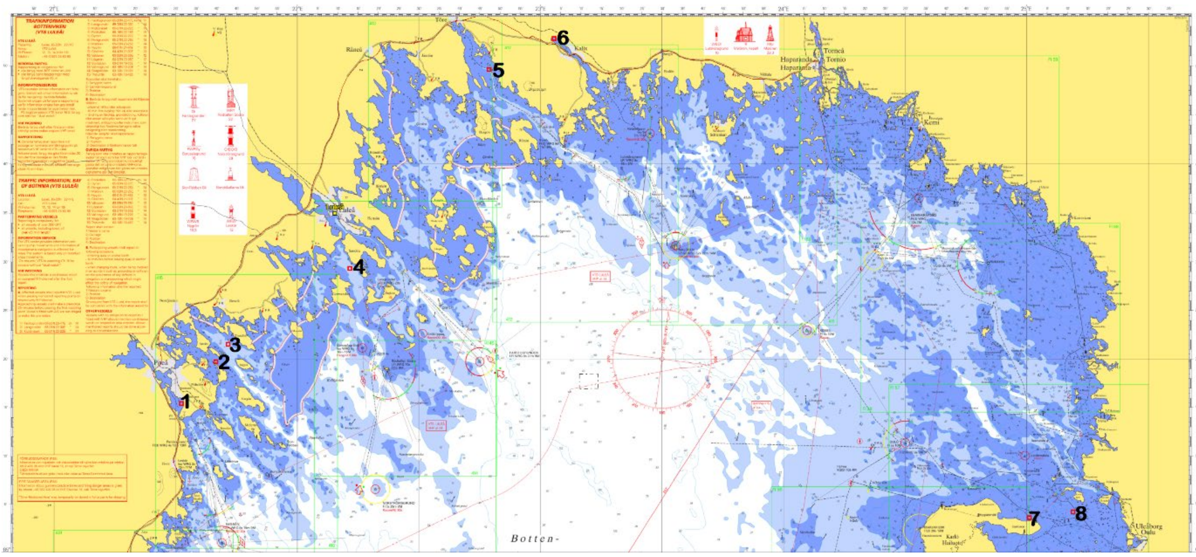

Figure 1. Sampling locations of spawning vendace for genetic analyses.

Sequencing and genotyping

A double-digestion restriction-site associated DNA (ddRAD) approach was then employed for SNP discovery and *de novo* genotyping (Peterson et al. 2012). PstI and ApeKI were used for restriction digestion and a paired-end sequencing (2 × 150 bp) was carried out on an Illumina NextSeq 500/550 v2 platform. SNP calling was carried out using Stacks v2.59 program (Catchen et al. 2013). Detected loci were filtered with Stacks v2.59 *populations* program setting option –r to 0.8 (minimum percentage of individuals per population required to process a locus), option -p 8 (minimum number of populations where a locus must be present) and option --min-maf to 0.05 (Minor allele frequency cutoff). For further analyses, additional filtering steps were applied with PLINK (Purcell et al. 2007), including samples call rate (--mind 0.2); global SNP call rate (--geno 0.1), and deviation form Hardy-Weinberg equilibrium (--hwe 2e-06).

Genetic diversity and structure

We evaluated genetic diversity in terms of the observed heterozygosity (H_O) and expected heterozygosity (H_E) calculated with *summary* function in the r package adegenet (Jombart, **2008**; Jombart et al., **2010**). The genetic differentiation among pairwise population was evaluated using the unbiased F_{ST} estimator (Weir and Cockerham 1984) in the StAMPP R package (Pembleton et al. 2013, Pembleton and Pembleton 2020). Significance of F_{ST} values and 95% confidence intervals were computed using bootstrap methods as implemented in the package. The number of population clusters was visualized using a discriminant analysis of principal components (DAPC) in the r package adegenet (Jombart, **2008**; Jombart et al., **2010**). Using the "optim.a.score" function to identify the best number of principal components (PCs) to retain. Too many or too few PCs can lead to low repeatability of results and over- or underfitting the data (Jombart et al., **2010**). We also inferred individual ancestry proportions with ADMIXTURE 1.3.3 (Alexander et al., 2009), for this analysis, we performed 500 bootstraps with a number of ancestral lineages (K) ranching from 1 to 20. Ten-fold cross validation (CV = 10) was specified, and we retained results from the K having the lowest cross-validation error. Finally, in order to represent the relationships among all vendace samples, a neighbor joining phylogeny was built using the Euclidean distance matrix from the *nj* function from R/ape (Paradis et al. 2004).

Results

Sequencing and genotyping

Eighteen individuals with the lowest read count were excluded from Stacks analyses. Therefore, we used 270 individuals for SNP calling process. Finally, 21,792 variants and 267 individuals passed filters and quality control steps and were used for genetic analyses.

Genetic diversity and structure

Diversity indicators showed similar patterns of diversity among populations (Table 1). Slightly higher expected heterozygosity compared to observed heterozygosity suggests some degree of inbreeding. The pairwise F_{ST} between 8 sampling location. The eight sampling locations yielded 28 possible comparisons, which were of which **23** were significant (*p*-value < 0.05) and ranged from 0.00**3** to **0.0096** (Table 2). The highest genetic differentiation was observed between Kalix river and Uleåborg offshore (F_{ST}= **0.0096**). Overall Kalix river showed to be more differentiated than the rest of the populations, which is congruent with DAPC plot (Figure 1), where most of individuals from Kalix river form a differentiated cluster. Individuals from Uleåborg offshore showed to be slightly separated in the DAPC along the second axis. The admixture analysis to determine the composition of ancestral lineages among individuals showed 5 ancestral lineages as the optimal for describing the ancestry of the individuals across the eight populations (Figure 3). Consistent with the DAPC and F_{ST}, Kalix river individuals are all relatively differentiated from the rest of the populations, showing a more homogenous pattern in terms of their ancestral proportions, being dominated by one ancestral lineage. The phylogenetic tree (Figure 4) confirmed that the individuals are not markedly diverged from one another, except for Kalix River, where samples formed a more differentiated cluster.

Table 1. Genetic diversity indicators for eigthe vendace samples in term of Observed Heterozygosity (H_O) and Expected Heterozygosity (H_E)

	N	H_O	H_E
Uleåborg offshore	36	0.2660	0.2673
Uleåborg coastal	19	0.2682	0.2721
Luleå	36	0.2703	0.2728
Piteå	35	0.2708	0.2732
Piteå river	36	0.2722	0.2740
Piteå coastal	36	0.2660	0.2735
Kalix river	35	0.2664	0.2707
Kalix coastal	34	0.2702	0.2724

Table2. Genetic differentiation expressed as pairwise F_{ST} (Weir & Cockerham 1984) using 21,792 SNPs.

	Uleåborg offshore	Uleåborg coastal	Luleå	Piteå	Piteå River	Piteå Coastal	Kalix River
Uleåborg coastal	0.0002	--	--	--	--	--	--
p-value	0.1997	--	--	--	--	--	--
Luleå	0.0007	0.0003	--	--	--	--	--
p-value	**0.0000**	0.0832	--	--	--	--	--
Piteå	0.0012	0.0006	-0.0001	--	--	--	--
p-value	**0.0000**	**0.0033**	0.7284	--	--	--	--
Piteå river	0.0008	0.0004	0.0002	0.0003	--	--	--
p-value	**0.0000**	**0.0301**	0.1481	**0.0361**	--	--	--
Piteå coastal	0.0011	0.0006	0.0004	0.0003	0.0000	--	--
p-value	**0.0000**	**0.0061**	**0.0132**	**0.0366**	0.4415	--	--
Kalix river	0.0096	0.0089	0.0084	0.0080	0.0081	0.0080	--
p-value	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	--
Kalix coastal	0.0012	0.0008	0.0005	0.0006	0.0003	0.0007	0.0080
p-value	**0.0000**	**0.0005**	**0.0013**	**0.0002**	**0.0288**	**0.0000**	**0.0000**

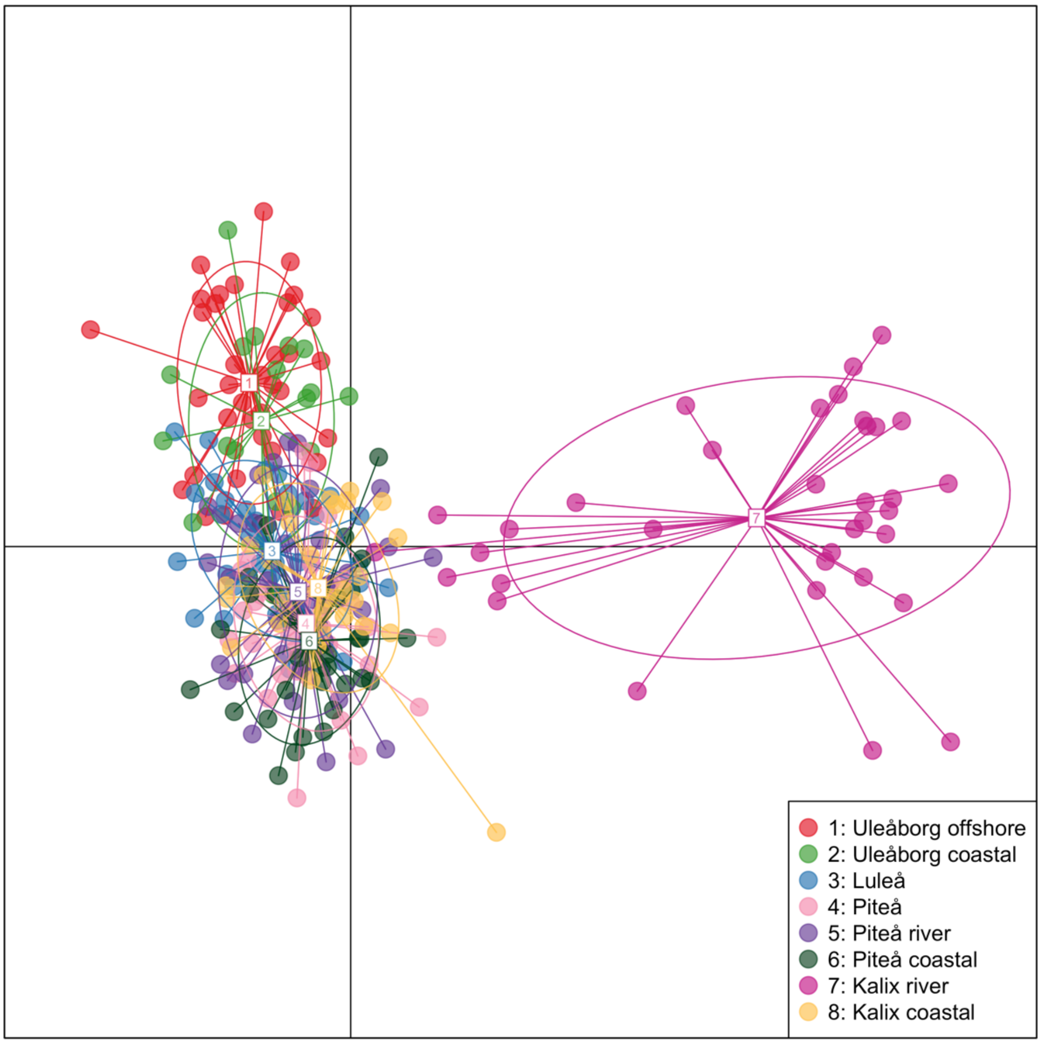

Figure 2. Discriminant Analysis of Principal Components (DAPC) of genetic differentiation. Individuals from different populations are represented by different colours.

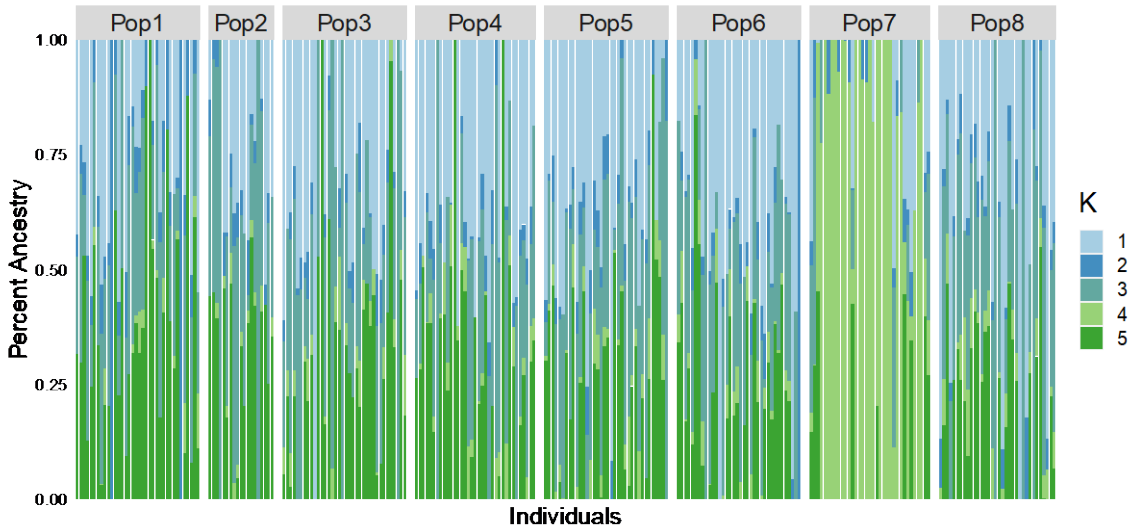

Figure 3. Individual assignment probabilities generated with ADMIXTURE (1⩽K⩽5). Each color represents a cluster, and the ratio of vertical lines represent the assignment probability of one individual to each cluster. Pop1: Uleåborg offshore; Pop2: Uleåborg coastal; Pop3: Luleå Pop4: Piteå; Pop5: Piteå river; Pop6: Piteå coastal; Pop7: Kalix river; Pop8: Kalix coastal.

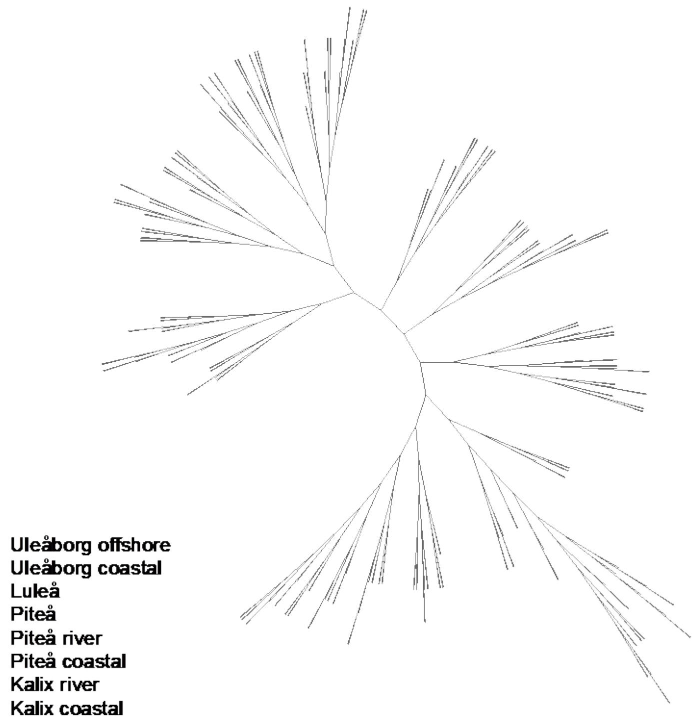

Figure 4. Neighbor joining phylogeny representing the relationship among samples from each population. Each population is represented by a different color.

Main conclusions and discussion points

- Overall differentiation among samples very low (as expected given large population sizes and dispersal ability of vendace).
- Two datasets differed in number of markers but showed congruent results. Samples from Kalix älv clearly differed and unique from the rest of samples. What is known about this sample/location/population?
- Second-largest genetic difference was observed between Swedish and Finnish samples. Needs to be confirmed with more samples/loci, especially from the Finnish side. Are differences large enough to consider them different stocks or should vendace in the Bothnian Bay be managed as one stock.
- Relate the results to the tagging studies from the 60-80s. Mixing between Finnish and Swedish stocks likely but low. Literature say that vendace spawn mainly in Sweden but

to a smaller extend also on the Finnish coast. The theory is that vendace make feeding migrations in summer also outside the fjords towards more nutritious waters. However, theory also proposes that it is mainly the large individuals who make it all the way to Finland and that the number of large individuals have decreased since the trawl fishery started in the 1960s. Thus the question still remains if the genetic difference notable in our analyses points to the requirement of separate or joint management of vendace off the Swedish and Finnish sides of the Bothnian Bay.

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