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Evaluation of the SEAT II joint-industry project

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Client:	Sustainovate AS Attn.: Mark Sytse Ybema Fiskekroken 14H, 0139 Oslo, Norway

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Contents

Summary

The SEAT algorithm aims at classifying different fish species using relative frequency response acquired by downward looking echosounders operating at multiple frequencies. The performance of the system has been being evaluated on three Dutch freezer trawlers: Fishing Vessel (FV) SCH302 Willem van der Zwan, FV SCH6 Alida and FV SCH24 Afrika. One of these vessels (FV Alida SCH6) operates a mixture of SIMRAD EK60 & EK80 software while others operate only Simrad EK80. As reported by these vessels, the classification accuracy of the SEAT software has been reduced particularly at the later stages of the project. To investigate this problem these vessels collected acoustic data in close range of each other while targeting herring in the summer of 2017 at east of Shetland isles. Using this dataset together with calibration data, a statistical comparison was conducted. Furthermore, potential discrepancies between Simrad EK60 and EK80 systems were examined using data collected during herring assessment survey HERAS of Fishing Research Vessel (FRV) TRIDENS in July 2017. This dataset included recordings of both systems in alternating mode enabling a ping to ping comparison. It was found that two serious software bugs were likely to have influenced the calibration procedure of the EK80 software. One of these impacted the comparison of HERAS FRV Tridens records and lead to Sv gain offsets of 1.76 dB. After the correction, the measured acoustic intensities were comparable between EK60 and EK80 implying that the interchangeable application of these tools on board SCH6 should not affect species classification and measurements should be similar between vessels either using EK60 or EK80 given the instruments are calibrated correctly. The calculated relative frequency responses from the acoustic recordings of these three fishing vessels showed that FV Willem van der Zwan SCH302 and FV Alida SCH6 were found reasonably coherent, but FV Afrika SCH24 was different. These differences are associated with lower mean backscatter values of the 38 kHz channel.

Similar analysis conducted in the earlier phases of this project where frequency response calculated from data collected by FV Alida SCH6 to investigate the discrepancies in the received horse mackerel frequency response and its expected fingerprints (Fassler, 2016 Annex 1). His results showed that the contribution of the 120 kHz data on the classification of varied with location and increased above latitude 52. In addition, this contribution was much lower for shoals detected in the English Channel (Fassler, 2016). Fassler (2016) also suggested that water pressure may affect the morphology of swimbladdered species and may explain the variability between shoals detected on the Atlantic Ocean and in the English Channel. The depth related effects found in different cases suggests that water depth has to be accounted for as an additional variable for each location. As suggested by Fassler (2016), these results may gain significance when the number of datasets increases.

The results of the investigations presented here show that further post-processing of calibration records may improve the data quality hence the classification outputs. Particularly the unexpected reduction in the classification performance after 2016 can be improved by rolling back all the SEAT settings to an original state followed by proper calibrations settings. It is also recommended to maintain the latest software versions to ensure equipment are operating efficiently and consistent across the vessels. Regular tests with vessels fishing in close range as in the case of the summer of 2017 is a useful approach to test species recognition and to compare overall performance of the classification algorithm.

1 Introduction

The joint-industry project SEAT (School Exploration and Analysis Tool) aims at developing a practical species identification tool based on recognition of acoustic signatures of fish recorded by using the vessel's hull-mounted echosounders. This is done through the use and improvement of the SEAT software (https://cmr.no/projects/10414/seat/). In a preceding project (SEAT I), species identification algorithms based on these echosounder data were used to assist skippers to decide on discrimination of mackerel and horse mackerel in areas of co-occurrence. The main purpose was bycatch reduction, specifically of mackerel in the horse mackerel fishery. In essence, the first phase of SEAT (I) can be seen as a feasibility study on identifying clean schools of mackerel and horse mackerel with the use of echosounders. SEAT (I) has identified a number of improvements that are necessary to further develop the SEAT algorithm into a useful tool for efficiently targeting pelagic main species and avoiding non-commercial catches, like boarfish. As a result of SEAT (I) a number of improvements were identified:

- Acoustic noise levels were more severe than anticipated and affected the classification performance as it is sensitive to the quality of the raw acoustic data;
- Other species occurring in the fishing area can affect correct classification of "target species". Without any knowledge about the scattering properties of these species, SEAT will misclassify them as one of the target species;
- Acoustic backscattering properties of species may vary with fishing seasons or areas. This variability will have to be considered to improve the performance of SEAT.

Within this context, echosounder equipment have been continuously improved on fishing vessels with increased resolution of acoustic data that assist decision making during fishing operation. In addition, real-time species recognition gained importance with the introduction of a discard ban in European waters. FV Alida SCH6 was the first fishing vessel involved in this joint-industry project SEAT (I) that started in 2012. In SEAT II acoustic data were collected from 2014 to 2017 by three commercial Dutch freezer trawlers: FV Alida SCH6, FV Afrika SCH24 and FV Willem van der Zwan SCH302. Analysis of these data is presently reported for the Wageningen Marine Research (WMR) related tasks consisting of data analysis with respect to the encountered issues. The project team consists of

- Sustainovate (NL, coordinator);
- Dutch freezer trawler companies, Van der Zwan, Scheveningen and Jaczon, Scheveningen;
- WMR (NL)
- CMR (NOR).

CMR is the owner of the SEAT software that implements the algorithm for species identification. Within the SEAT project, the data base for the SEAT algorithm is regularly increased with selected data collected by the three FVs. This directly improves the species identification algorithm with increased robustness for already existing species in the database but also add new species to be classified. On each FV, the SEAT software is installed on a specific computer. Within the SEAT (II) project, WMR is partly involved for specific assessment tasks dealing with: (1) calibration of echosounder equipment; (2) raw data assessment; (3) technical advices on echosounder equipment and noise reduction. As part of the allocated WMR tasks in the SEAT (II) project, two unregistered WMR reports were submitted to the commissioner by Sasha Fassler: in 2016 (Annex I, referenced as (Fassler, 2016) in this report) and early 2017 (Annex II, referenced as (Fassler, 2017) in this report). Fassler (2016) reported variation in horse mackerel acoustic fingerprints while Fassler (2017) focused on the difference in acoustic fingerprints between horse mackerel and herring in the English Channel.

Outcomes of a meeting held on 11 July 2017 at the office of Van der Zwan, Scheveningen (NL) drawn attention to the reduced efficiency of the SEAT software since 2017 and the staff of fishing vessels lost confidence in the software. This decreased performance led the project team to raise doubts on the compatibility between different echosounder data sets. Although these vessels use similar echosounder with multiple frequencies, there is some hardware and software related differences. The hardware may consist of a mixture of GPT (General Purpose Transceiver) and WBT (Wide Band Transceiver) transceivers with respectively SIMRAD EK60 and EK80 operating systems (FV Alida SCH6) or have a different 38 kHz transducer (FV Afrika SCH24 ES38-7, while the other two vessels operate the ES38B). The EK80-WBT transceiver supports a dual operational mode, in which either Continuous Wave (CW) mode, in which a single frequency is outputted, or a Wide Band (WB) operational mode, consisting of a wider band of frequencies (WB-mode). In the SEAT (I) and (II) projects, only CW data are used. Unless specified, EK80 will refer to EK80 CW. As a recommendation of the meeting of 11th July 2017 it was decided to investigate vessel-specific acoustic conditions. For this experiment a single North Sea cruise was used with all three vessels targeting herring in close range of each other.

2 Methods and procedures

The decline of the classification success as reported by skippers assumed to be due to following reasons: a) discrepancy between different systems namely EK 60 and EK80 b) uncertainty of the calibrations c) unexplainable factors such as changes in the fish physiology affecting the body material properties. First, the effect of potential differences between EK60 – EK80 was investigated. It was followed by an investigation of the FV calibration files that were available to WMR within the project period. Finally, a comparison was carried out between dataset collected by FVs, focusing on an area in the North Sea where monospecific herring aggregations were found.

2.1 Comparison between SIMRAD EK60 and EK80

The consistency between the EK60 and the EK80 systems were compared using a dataset collected by FRV Tridens II in July 2017 during the HERAS acoustic survey (ICES, 2017). On FRV Tridens, both the EK60 and the EK80 transceivers can be operated in alternating mode to drive the same hull-mounted transducers (18 kHz, 38 kHz, 70 kHz, 120 kHz, 200 kHz and 333 kHz) in a ping to ping sequence using an electronic switch and the K-Sync Kongsberg system. This setup enabled the acquisition of acoustic data for both the EK60 and the EK80 at few milliseconds intervals, having both systems virtually ensonifying the same sample volume. The results of this test considered to provide a reliable basis also for other vessels operating in the same area using EK80. These data were assessed in Echoview and consisted of records of 5 hours over 3 different days. Procedures described in detail in the appendix section involved careful assessment of the calibration records (Annex III). Some errors in the calibrations records were found and fixed. As a result these systems were considered comparable. This is an important step to rule out potential effect of using different types of echosounders (i.e. EK80 and EK60.). However it is important to note that this is a limited data set and similar tests are ongoing as part of WMR internal projects with expected new datasets to be collected.

2.2 Calibration records

Although EK60/EK80 differences were ruled out, some calibration related problems were found during this exercise. These were related to the EK80 software. Because it is also likely to have similar problems on the FVs, we were incentivized to look at historical calibration records of the FVs. Furthermore, frequent software/firmware upgrades in EK80 made the calibration accuracy somewhat dubious. For these reasons, we crosschecked results in various calibration trials carried out by the FVs.

2.2.1 Importance of the calibration and implications

For a species identification method using multiple frequencies such as SEAT, accurate calibration is paramount. The SEAT algorithm relies on frequency response signatures of different species categories with predefined error margins. During operation, the real-time measurements are compared against predefined reference signatures of the target species and classification decision is made based on the likelihood of the received signal. For example a fish species without swim bladder (e.g. Atlantic mackerel) is expected to scatter sound more strongly in the higher frequencies, resulting in an increased frequency response curve with increasing frequencies. These species-specific frequency response curves were previously established for several species (Fernandes 2009, Fernandes et al., 2006, Korneliussen et al., 2009, Fassler et al 2007). The origin of the differences in frequency response shapes are assumed to originate from physical characteristics of the species body (e.g. fish with/without swim bladder) because the body material properties is closely related to the sound scattering properties (e.g. density and compressibility of the body components). Therefore, acoustic classification capitalizes on the premise that different species will have characteristic curves. However, because measurements at each frequency are carried out by a different transducer, any changes in the performance of transducers will also affect the shape of the curve. As a result, the consistency of the measurements needs to be ensured and maintained by regular calibrations. In the case of using an uncalibrated (or erroneously calibrated) transducer, the consistency of the frequency response cannot be ensured, potentially leading to a decline in species identification success rate that cannot be traced. The change in the calibration parameters over time can be due to: aging of the system, changes in the vessel electronics, changes in the environmental conditions or any other potential physical or electromagnetic effects.

2.2.2 Calibration Procedure

For scientific purposes, echosounders are typically calibrated before each survey. Indeed, the manufacturer of the equipment (Simrad) does not guarantee the accuracy of the measurements unless the equipment is calibrated within the same spatiotemporal context with representative environmental conditions. Calibration of an echosounder is carried out by measuring a standard metal sphere with known reflectivity properties (Demer et al., 2015, Foote et al., 1987). During the calibration, the sphere is lowered underwater while all environmental factors are isolated (e.g. temperature and salinity are measured, no interference is ensured). At the end of a calibration, the measurements are compared with expected theoretical values expected from the reference sphere. In the case of a difference from the expected values, calibration offset parameters are calculated and corrections are applied subsequently. These corrections consist of ***gain*** and ***Sa correction*** *(see explanations (section 2.2.3.1) for these terms and Demer et al. (2015) for further details*). Calibration trials set reference points for the validity of acquired data and ensure that the received frequency response curves are independent from equipment or platform.

2.2.3 Calibration files

"Calibration file" can refer to different type of files in this study. These include "raw calibration files", EK60 "TrList.ini" text files, EK80 "XML" files and SEAT "XML" files used for post-processing.

- **Raw file:** these are unprocessed digital power recordings of Simrad echosounders recorded as specific binary ".raw" format. As this data consists of unprocessed raw signal records, they are not directly usable for calibration settings, unless post-processed to derive /check /validate the calibration parameters. These files contain all necessary information including angular positions and power for each beam of transducer and frequency channels. This data can be reprocessed for calibration either using Simrad software or other post-processing software such as Echoview.
- **EK60 "TrList.ini" and EK80 "XML" files:** these files contain post-processed information and final calibration results and metadata about the calibration e.g. time, position, environmental parameters acoustic setting etc. The critical values in these final parameters are TS gain and Sa correction.EK80 XML files additionally contain ping by ping measurements of the calibration sphere. As a result, it is possible to re-calculate the calibration parameters from the EK80 xml files however it would not be possible to perform a detailed reanalysis such as noise/spike removal.
- **SEAT XML files:** this is an application specific file where the calibration parameters are entered for post processing. Typically the gain and Sa correction parameters are copied from EK60 "TrList.ini" or EK80 "XML" files and pasted into this file to be read by SEAT and no modification recalculation is applied.

For our analysis, not all of the raw files from the latest calibration trials were available to WMR. Therefore our assessment focused on the datasets that are stored in WMR servers. These are:

- *FV Afrika SCH24* (05-August-2016)
- *FV Willem van der Zwan SCH302* (16- 17 - October - 2015)
- *FV Willem van der Zwan (*17-19- August - 2016)

These datasets contained both xml and raw files. A conceptual diagram describing the use of different data types for functionning of the SEAT software is shown in ***Figure 1***.

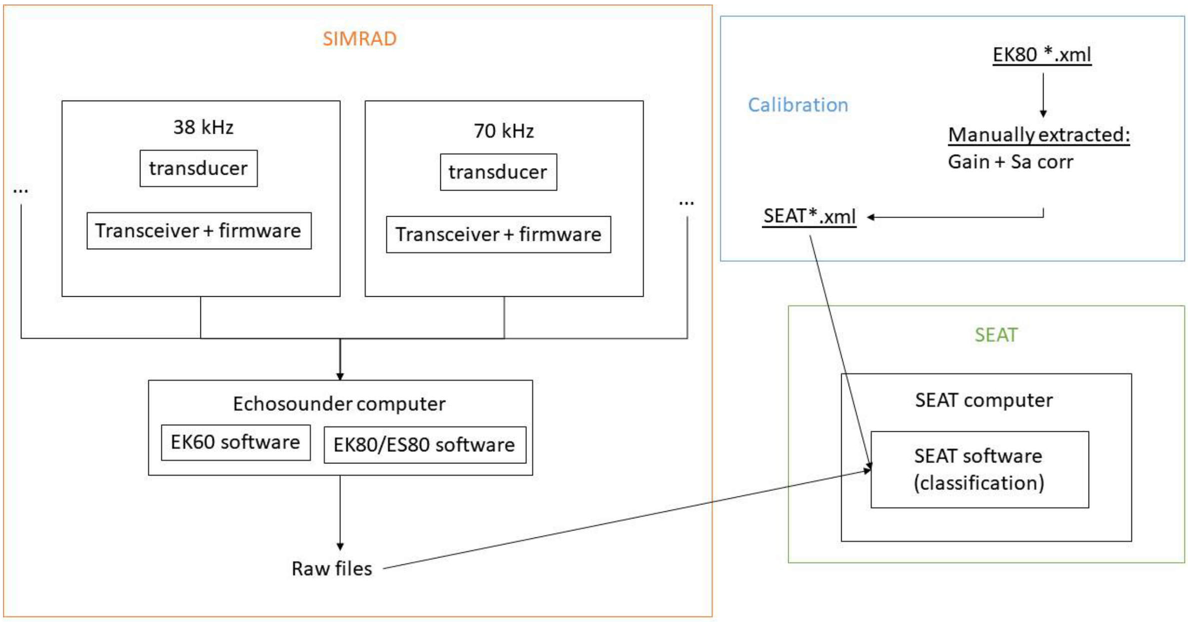

Figure 1 Schematic description of the data acquisition and application of calibration parameters for subsequent use in the SEAT software.

***Table** 1 Software and firmware versions as recorded in the EK80 XML calibration files*

Vessel	Frequency	Software	Firmware	Date
SCH24	120 kHz	1.10.6058.1634	1.7	20160805
SCH24	18 kHz	1.10.6058.1634	1.7	20160805
SCH24	200 kHz	1.10.6058.1634	1.7	20160805
SCH24	333 kHz	1.10.6058.1634	1.7	20160805
SCH24	38 kHz	1.10.6058.1634	2.11	20160805
SCH24	70 kHz	1.10.6058.1634	1.7	20160805
SCH302	120 kHz	1.10.6058.1634	1.7	20151016
SCH302	18 kHz	1.8.0.0	1.7	20151017
SCH302	200 kHz	1.8.0.0	1.7	20151017
SCH302	38 kHz	1.8.0.0	1.7	20151016
SCH302	70 kHz	1.8.0.0	1.7	20151016
SCH302	18 kHz	1.8.3.0	1.7	20160818
SCH302	200 kHz	1.8.3.0	1.7	20160818
SCH302	333 kHz	1.8.3.0	1.7	20160818
SCH302	38 kHz	1.8.3.0	1.7	20160818

***Table 2** Calibration parameters as recorded in EK80 XML files. These are automatic calculations produced by EK80 calibration software.*

Frequency (kHz)	TS mean (dB)	Ref (mm)	Ref TS (dB)	Previous Gain (dB)	New Gain (dB)	Sa Corr (dB)	Sv gain (dB)	Sv Mean (dB)	Range (m)	Ψ (dB)
SCH24 (2016)										
18	-32.32	63cu	-34.6	22.4	23.58	-0.21	23.37	-41.99	19.36	-17
38	-42.37	38.1	-42.44	26.5	26.66	-0.11	26.55	-45.67	15.27	-20.6
70	-38.93	38.1	-41.44	27	28.23	-0.02	28.21	-42.32	16	-21
200	-37.09	38.1	-39.22	27	28.06	-0.08	27.98	-40.54	15.67	-20.7
333	-40.2	22	-43.75	24	24.86	0.06	24.92	-40.91	11.93	-20.7

FV Willem van der Zwan SCH302 (2015)										
18	-34.69	63 cu	-34.6	15.8	18.91	-0.13	18.78	-48.81	25.32	-17
38	-44.28	38.1	-42.44	26.5	25.53	0.06	25.59	-49.29	15.6	-20.6
70	-38.86	38.1	-41.44	27	28.2	-0.04	28.16	-41.31	12.98	-21
120	-42.32	38.1	-39.47	27	25.32	-0.32	25	-48.18	18.74	-20.7
200	-38.32	38.1	-39.22	27	27.5	-0.04	27.46	-41.79	13.73	-20.7
FV Willem van der Zwan SCH302 (2016)										
18	-44.44	63 cu	-34.6	22.4	18.1	-0.15	17.95	-51.3	17.06	-17
38	-39.79	38.1	-42.44	26.5	27.85	0.01	27.86	-42.96	15.12	-20.6
70	-38.8	38.1	-41.44	27	28.29	0	28.29	-40.02	12.71	-21
200	-36.39	38.1	-39.22	27	28.13	-0.04	28.09	-36.33	11.5	-20.7
333	-35.74	22	-43.75	24	26.48	0.06	26.54	-35.14	10.38	-21

Table 3 *Calibration parameters derived by manual calculations using Echoview postprocesing software. Explanations of the headers are given below the table.*

Frequency (kHz)	Range	Sv Theory (dB)	TS Theory (dB)	Ref (mm)	TS gain manual (dB)	SaCorr manual	Sv offset	TS Offset	Sv gain manual (dB)
SCH24 (2016)									
18	19.36	-44.13	-34.6	63Cu	23.54	-0.07	1.07	1.14	23.47
38	15.27	-45.52	-42.44	38.1WC	26.54	-0.11	-0.08	0.04	26.42
70	16	-44.52	-41.44	38.1 WC	28.26	-0.15	1.1	1.26	28.1
200	15.67	-42.42	-39.22	38.1 WC	28.07	-0.12	0.94	1.07	27.94
333	11.93	-44.58	-43.75	22 WC	25.78	0.06	1.84	1.78	25.84
FV Willem van der Zwan SCH302 (2015)									
18	25.32	-48.05	-34.6	63 cu	15.76	-0.34	-0.38	-0.04	15.42
38	15.6	-47.46	-42.44	38.1 WC	25.58	0.01	-0.91	-0.92	25.59
70	12.98	-43.81	-41.44	38.1 WC	28.29	-0.04	1.25	1.29	28.25
120	18.74	-44.91	-39.47	38.1 WC	25.58	-0.21	-1.64	-1.43	25.36
200	13.73	-42.51	-39.22	38.1 WC	27.45	-0.09	0.36	0.45	27.36
FV Willem van der Zwan SCH302 (2016)									
18	17.06	-41.16	-34.6	63 cu	17.48	-0.15	-5.07	-4.92	17.33
38	15.12	-45.43	-42.44	38.1 WC	27.83	-0.09	1.24	1.33	27.74
70	12.71	-42.52	-41.44	38.1 WC	28.32	-0.07	1.25	1.32	28.25
200	11.5	-39.73	-39.22	38.1 WC	28.42	0.29	1.7	1.42	28.7
333	10.38	-43.07	-43.75	22 WC	28.01	-0.04	3.97	4.01	27.97
333*		-36.13	-36.81	38.1 WC	24.54	-0.04	0.5	0.54	24.5

The headers of Table 2 and Table 3 are as follows; ***Range****: extend between transducer and calibration sphere.* ***Sv Theory****: Theoretical Sv calculated based on range and theoretical TS of the sphere.* ***Ψ****: Equivalent two way beam angle (a value reported by manufacturer).* ***Ref****: size and material of the reference sphere (Cu = Copper, WC= Tungsten carbide).* ***Previous Gain****: Gain from previous calibration trial.* ***TS gain manual****: Average TS extracted and calculated from raw data using Echoview.* ***SaCorr****: Sa correction calculated automatically by EK80 software.* ***SaCorr manual****: Sa correction calculated from raw data using Echoview.* ***Sv/TS Offsets****: Differences of the measurements relative to the theoretical values.* ***Sv gain manual****: Manually calculated gain from the parameters within this table.*

** Note: the second row of the 333 kHz channel of FV Willem van der Zwan SCH302 in Table 3 shows an additional manual calculation by changing the reference sphere parameter from 22 mm (WC) to*

38.1 mm (WC). The reason for this the resulting high offset was dubious. Use of 38.1 (WC) sphere in calculations improved the results (i.e. lower offset). This is explained further in the results.

Important note: *In the next section a comparison between datasets collected by each fishing vessels are presented. However, not all the parameters presented in this calibration section are applicable in the further section consisting of data analysis. There are two reasons; Firstly, we have been informed that an additional calibration was performed by the crew of FV Willem van der Zwan SCH302 in 2017 and SEAT parameters modified accordingly. However we did not have access to this raw calibration dataset so the results are not verified. Secondly, the crew of FV Alida SCH6 also capable of autonomously calibrate the echo-sounders and they do it relatively frequently. Unfortunately we did not have access to any calibration file of this vessel. Only calibration parameters that are applicable for the comparison study in the next section are those of FV Afrika SCH24. However this calibration was almost one year old at the time of data collection hence cannot be considered valid.*

2.2.3.1 Additional explanation on calibration parameters:

Gain: the transducer gain shows the amount of energy lost by the instrument itself during the conversion. More specifically, conversion between electric and acoustics is never 100% efficient and a portion of the energy is also lost within the instrument during the sending and receiving processes. For example when electrical input is converted to acoustic energy in the form of acoustic waves, some of the energy is lost into heat. Similar loss happens when the scattered acoustic waves are being converted back to electrical energy. Normally this gain factor of the instrument is provided by the manufacturer. However potential changes are tracked through calibration trials using calibration spheres (Demer et al 2015, Foote et al. 1987). Normally expected magnitude of the returning sound from a calibration sphere is precisely known. Additionally, it is possible to theoretically calculate the amount of losses in the water column (e.g. spreading and absorption). The remaining unknown is the loss due to transducer efficiency. To account for this deficit in the energy budget, some amount of amplification needs to be applied to the received signal. This amplification is the transducer gain. Higher gain means higher transducer efficiency therefore lower amplification. Lower gain means lower efficiency hence more amplification is applied to compensate for the loss.

Sa correction is an additional parameter to account for potential discrepancy between TS and Sv (MacLennan 2002). This difference is generally due to variation in the effective pulse length which is potentially different from the transmitted pulse length. However EK80 accounts for the effective pulse length hence the Sa corrections for the EK80 are expected to be very low.

2.3 Inter-vessel comparison

Acoustic data were collected during the fishing operation of three freezer trawlers participating in the SEAT (II) project: FV Afrika SCH24 and FV Willem van der Zwan SCH302 and FV Alida SCH6. This trial happened over July and August 2017. Data used in this study are those collected on 17th and 18th August 2017, period over which all three vessels were fishing in close range of each other (south of the Shetland Islands, see ***Figure 2***). From the collected data, calculated frequency responses that are associated with herring aggregations were compared. Calibration parameters were taken from SEAT calibration files provided by Sustainovate which are the latest inputs for the SEAT (**Table 4**). It is important to note that these are not the original calibration files outputted by EK60 or EK60 software. Data processing involved several steps as described below.

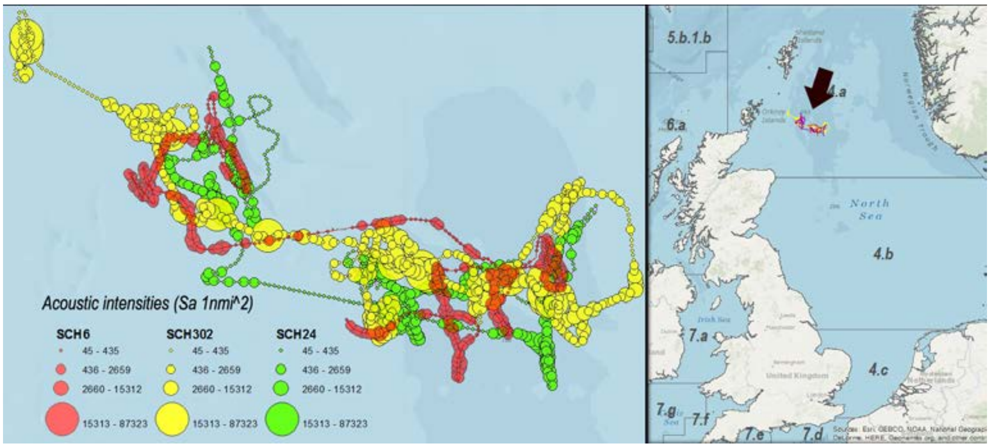

Figure 2: *Locations of the vessel cruise tracks and the acoustic intensities.*

Table 4: *Calibration parameters (gain and Sa correction) used for the inter-vessel comparison. The values for the 18 kHz channel of FV Willem van der Zwan SCH302 is the factory default value (corrected from original value of 24.5 dB). The reason this change in gain is because 24.5 dB was an unrealistic deviation from the factory default gain (22.4 dB).*

Fishing Vessel	18 kHz	38 kHz	70 kHz	120 kHz	200 kHz	333 kHz
			GAIN (dB)			
FV Alida SCH6	22.22	26.61	26.84	26.67	26.76	Nan.
FV Afrika SCH24		26.58	28.23	27.24	28.07	24.95
FV Willem van der Zwan SCH302	22.4 (Factory Default) (original = 24.5)	27.75	28.31	27.01	27.90	27.41
			Sa correction (dB)			
FV Afrika SCH6	-0.71	-0.56	-0.45	-0.29	-0.26	
FV Afrika SCH24		-0.11	-0.02	-0.08	-0.07	-0.07
FV Willem van der Zwan SCH302	-0.12	-0.01	0	-0.32	-0.03	0.05

The gain parameters for FV Willem van der Zwan SCH302 for the 18 kHz channel differed from the factory defaults (22.4 dB) by 4.6 dB (see ***Table 1***). Such a deviation from factory default is unusual and could not be explained. In a later stage it was brought to our attention that the calibration trials were affected by a software bug (i.e. while calibrating in WB-mode). Therefore, the factory default gain of 22.4 dB was used.

2.3.1 Processing steps

For this comparison the hydroacoustics post-processing software LSSS and Echoview were used for data processing and meta data extraction. For the data analysis R and ArcGIS were used. Processing of the raw acoustic data involved the following steps:

- FV Afrika SCH24 and FV Willem van der Zwan SCH302 use ES80 and records the raw data through SEAT after some data reduction. Then the format of the reduced data can only be read in LSSS. For this reason, these raw files were exported to standard text format (CSV) using LSSS and then imported into Echoview for further post-processing. FV Alida SCH6 data could be imported to Echoview directly as it is stored in the original format collected by EK60.
- The vertical resolution was adjusted to 20 cm by averaging for all vessels at all frequency channels.
- Data initially were inspected using the 38 kHz channel prior to school detection. This initial assessment showed herring schools constrained below a subsurface layer (for both night and

day), boundary most probably related to the seasonal thermocline (high temperature gradient in the water column). This subsurface layer was typically observed at depths of 30-40 m and seemed to be dominated by small-weakly scattering targets such as zooplankton and fish larvae. In order to better constrain fish school detection to Herring the aforementioned shallow scattering layer was removed by drawing a depth line manually. At night time, the herring aggregations formed diffuse layers below the subsurface layer. During day time the herring aggregations migrated downward, few meters above the seafloor.

- Data below 0.5 – 1 m offset from the sea bed were removed.
- Noise (as spikes) cleaned using a combination of impulse noise and transient noise filters, a method by Ryan et al. (2015) implemented in Echoview. These filters particularly eliminated the interference noise coming from other acoustic equipment such as omnidirectional sonars. A fish school masking procedure similar to Korneliussen et al., (2016) was implemented using image erosion – dilation image manipulators and derived Boolean masks for fish schools. This is a pre-processing step to refine the echograms so that fish schools becomes more obvious while weak or scattered other targets that are not likely to be fish schools are removed.
- The previous masks are then refined by running the Echoview fish school detection tool. This is a conditional test where the dimensions of the data point aggregations are compared against some thresholds such as length height and patch distances Each school detection were further verified manually (**Figure 3**). The pixel groups that meet these criteria are identified as schools and encircled by automatically drawn lines. Overall similar procedures were repeated as in Korneliussen 2016 which is the method that SEAT uses.
- Trawl catch information together with acoustic records (with school detections) from FV Afrika SCH24 were used for identifying the different types of school patterns (e.g. morphology, acoustic intensity distribution etc...) assignable to herring. Similar patterns then selected at the un-trawled regions of the acoustic recordings and for the data of other vessels.
- Acoustic densities S_a (MacLennan et al., 2002) were exported for each fish school with an integration distance of 1 nautical mile (nmi).
- The effect of different sampling unit distances, 0.1 nmi, 0.5 nmi, 1 nmi, 2 nmi, 3 nmi, 4 nmi, 5 nmi and 10 nmi. to the variation in the data was investigated using a non-parametric Kolmogorov–Smirnov (K-S) test. K-S test is a commonly used statistical test for checking the normality in distribution or comparing different statistical distributions. This is a test similar to student's t-test however using non-parametric method. In the specific case of this study, the statistical distribution of samples can be affected by sampling distance. Normally larger sampling distance would be more representative as it averages more schools. But may have more skewed distribution due to low number of samples. Too small sampling distance may end up producing outliers and data becomes noisier. Therefore it is desirable to achieve a balance between statistical representatives of the sample size as well as normality in distribution. Finally, 1 nmi distance was used or the further tests.
- The entire collection of exported herring S_a data with 1 nmi distance intervals. The frequency response was calculated as the dB difference relative to 38 kHz for each fish school.

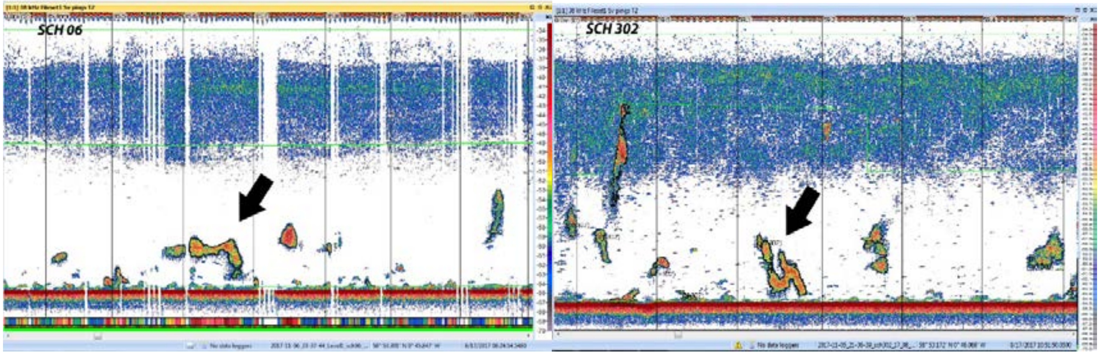

Figure 3: *Echograms of a fish school recorded by FV Alida SCH6 (left figure) within 170 m distance of a similar registration of FV Willem van der Zwan SCH302 (right figure) at an average depth of 110 m in the morning time with 2 hours of difference (SCH6 8:30am UTC – SCH302 10:50am UTC)*

3 Results

3.1 Comparison between EK60 and EK80

Because FV Alida SCH06 combines the use of the EK60 and the EK80, a thorough comparison of the both systems was conducted using a high data quality baseline data set (FRV Tridens, 2017 HERAS survey). This is presented in Annex III. A scrutiny of EK80 data from FRV Tridens showed calibration related discrepancies. This was due to a bug in the EK80 version 1.10.3, resulting in an error of 1.76 dB in S_a correction. After correction of this error, a very good correlation between the measurements from the EK60 and the EK80 was found (Figure III.4). In short, this analysis showed that the two systems produce comparable results ruling out the potential effect of different echosounder model usage.

3.2 Investigation of calibration parameters

The following issues associated with calibration trials were identified:

- For the calibration of FV Willem van der Zwan SCH302 performed on 18 August 2016, the resulting calibration outputs for the 333 kHz channel were erroneous. This was due to incorrect sphere selection in the EK80 calibration software by the operator. The 38.1 mm Tungsten carbide sphere was insonified, while the reference sphere selected in the calibration menu was a 22 mm Tungsten carbide sphere. Re-analysis of the raw calibration records using Echoview revealed that this resulted in an offset error of 2.65 dB for the gain (***Figure 4*** (a)). The detail of this is shown on **Table 3** second row of 333 kHz channel of FV Willem van der Zwan SCH302 marked with the asterisk. During calibration, several spheres were lowered in the water at different depths and it is likely that a confusion in the interpretation of the depth of the different spheres occurred. This was probably overlooked by the operator during the calibration procedure.
- For FV Afrika SCH24 initial calibration results were found to be consistent with the independent calculations with Echoview except from the 333 kHz with 0.9 dB difference. The reason for this difference cannot be explained. The calibration parameters in the SEAT XML file were also consistent with these records.

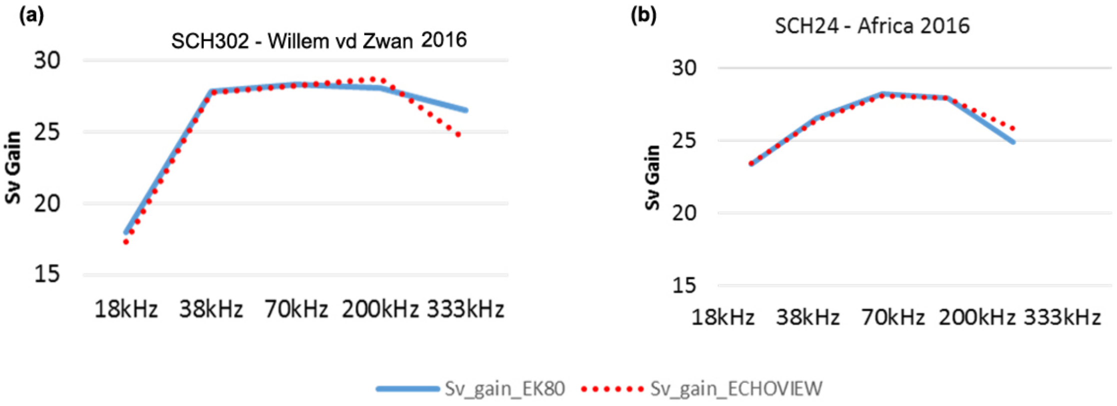

Figure 4: *Calibrations of FV Willem van der Zwan SCH302 and FV Afrika SCH24 in 2016, EK80 software and Echoview results compared. Details are presented on Table 2and Table 3*

3.3 Comparison of frequency response

3.3.1 Relative frequency response r (f) comparison results

The relative frequency responses for the different fishing vessels are presented in ***Figure 5***. It can be observed that the relative frequency responses of FV Alida SCH6 and FV Willem van der Zwan SCH302 are similar to each other. The trend of the frequency response for FV Afrika SCH24 also shows similarities to the other vessels at higher frequencies. However, the average backscatter (S_a) for 38 kHz is much lower compared to the other vessels (1.88 times less than FV Alida SCH6, (see Table 5 and ***Figure 6***). This results in a significant offset of the frequency response curve of FV Afrika SCH24 for frequency channels higher than 38 kHz. There is also a significant difference between relative frequency response of 18 kHz between FV Willem van der Zwan SCH302 and FV Alida SCH6.

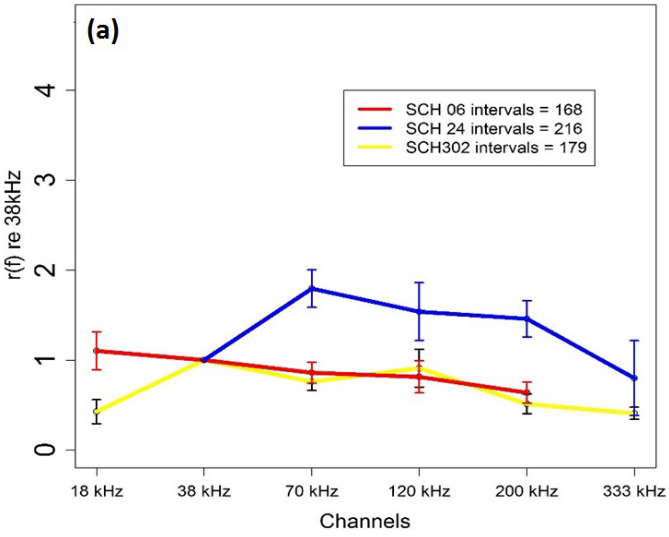

Figure 5: *Averaged frequency response for different FV. Vertical error bars show one standard deviation range.*

Table 5 : *Average Sa values compared between vessels for each frequency channel (e.g. SCH6_18 ~ SCH302_18 is the comparison between the 18 kHz frequency channel for FV SCH06 and FV Willem van der Zwan SCH302). Higher P-values imply lesser difference between the mean values. For the values above 0.05 it can be considered that the difference is negligible. In the right column of the table Means Sa-1 and Mean Sa-2 are referring to the first and second entry of the middle column which are the pairs compared.*

P-value	**Comparison (mean1 ~mean2)**	**Mean *Sa*-1**	**Mean *Sa*-2**
0.00042	SCH6_18 ~ SCH302_18	1079	603
0.085	SCH6_38 ~ SCH302_38	946	1269
0.341	SCH6_70 ~ SCH302_70	842	990
0.018	SCH6_120 ~ SCH302_120	816	1246
0.61	SCH6_200 ~ SCH302_200	636	694
1.07E-05	SCH24_38 ~ SCH302_38	502	1269
0.616	SCH24_70 ~ SCH302_70	910	990
0.012	SCH24_120 ~ SCH302_120	799	1246
0.739	SCH24_200 ~ SCH302_200	732	694
0.255	SCH24_333 ~ SCH302_333	426	512
3.83E-05	SCH6_38 ~ SCH24_38	946	502
0.594	SCH6_70 ~ SCH24_70	842	910
0.892	SCH6_120 ~ SCH24_120	816	799
0.331	SCH6_200 ~ SCH24_200	636	732

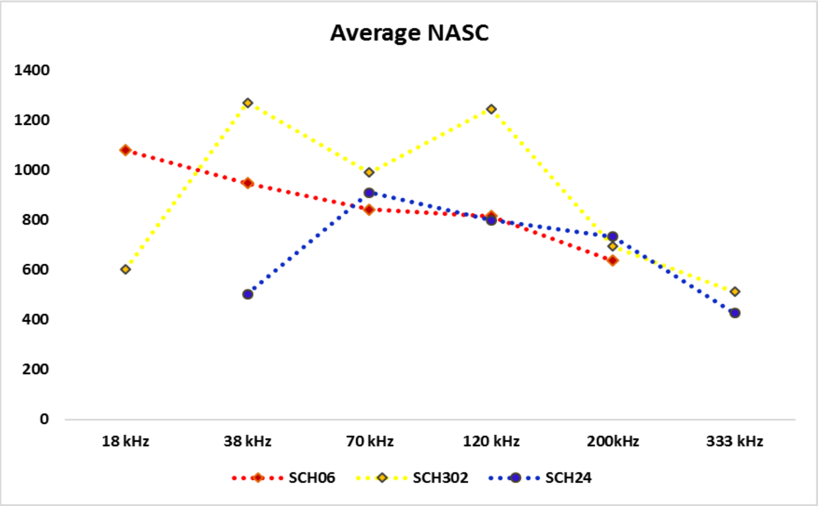

Figure 6: *average $S_{a\ (NASC)}$ values as provided on the Table* ***5***

3.3.1.1 Depth dependence of the relative frequency response

The effect of the depth on the frequency response was tested with a linear model and results showed a noticeable effect on 120 kHz (**Figure 7**). Table 6 shows the inferred slope from the linear fit and the significance of the effect. At 70 kHz the slope is 0.001 or lower meaning that the effect of the depth is negligible (0.4 dB difference from 40m and 140 m). In 120 kHz 0.004 dB makes 1.5 dB changes from 40m to 140m which may have visible effect on the shape of the r (f) curve. It is also interesting that the slope is negative at 18 kHz. However, it is also important to note that, these values are relative to the response of 38 kHz therefore not independent from its variability. The slope mentioned here is the slope of the fitted line rather than the actual points. The “p” value show whether the fit have a slope different from zero just by chance or it is a real effect (e.g. if same measurements are repeated or more data points added, the slope of the line remain greater than 0). The significance is a relative term such that if it is smaller than a specified threshold, e.g. 0.05 or 0.01 it is considered significant. In this case, although the slope of 70 kHz was also significant its effect can be very small (e.g. 0.4 dB change in r (f) in 100m of change in depth). Such change in 120 kHz is expected to be 1.5 dB which can be important for the species classification.

Table 6 *: Relationship between depth and relative frequency response. *** shows where the relationship is very significant.*

	SCH6		SCH24		SCH302	
Frequency (kHz)	slope	P-value	slope	P-value	slope	P-value
18	0.000	0.822			-0.003	***
70	0.001	0.001	0	0.611	0.001	***
120	0.004	***	0.004	***	0.003	***
200	0.002	***	0.002	***	0.001	0.097
333			0.003	***	0.001	***

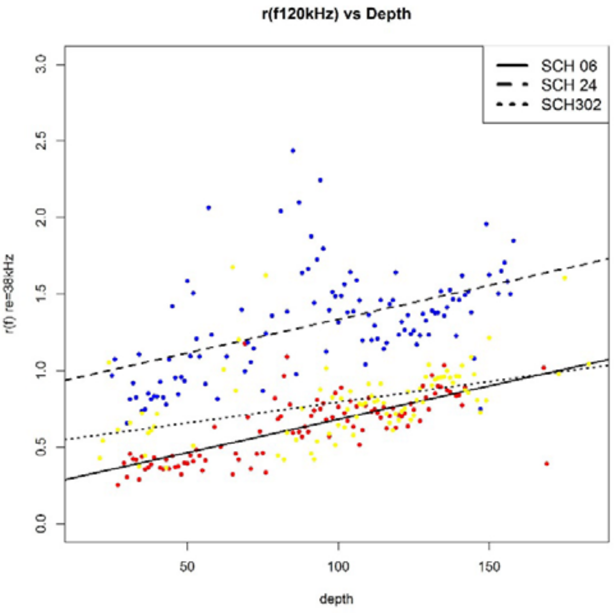

Figure 7 *the relationship between depth and relative frequency response at 120 kHz for the different fishing vessels. The Y axis shows r (f) of 120 kHz relative to 38 kHz. Points indicate the average r (f120 kHz) for each 1m depth bin*

1.1 Additional observations

LSSS vs Echoview: A test was performed to investigate whether the fingerprints produced with Echoview were consistent with the LSSS tool (Figure 8). The results showed that the outputs are identical, ruling out any potential post-processing software related discrepancies.

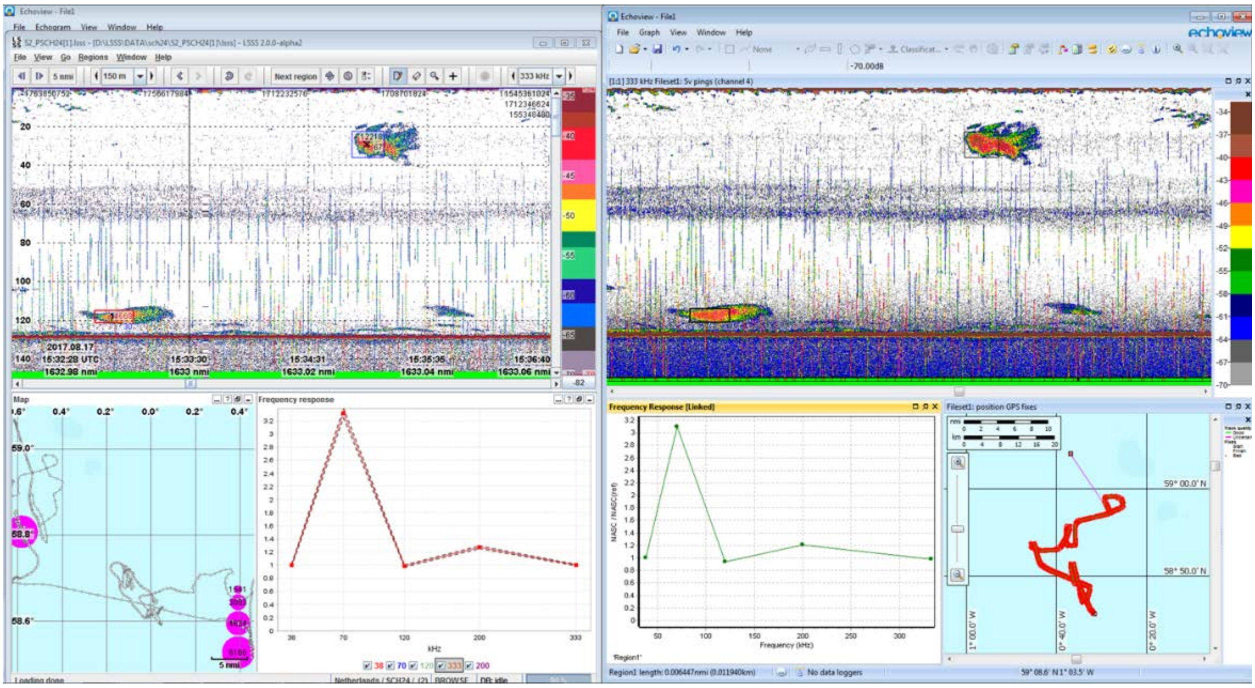

Figure 8 *Comparison of LSSS and Echoview for the fingerprints. For a section of same school near the bottom both post-processing program produced identical fingerprints.*

4 Conclusions and recommendations

4.1 Comparison and vessel related effects

Comparisons show that a significant offset exists in FV Afrika SCH24 for the 38 kHz channels. This is most likely due to a calibration error and/or system related discrepancy for this specific channel. Although the latest calibration files of SCH302 and SCH6 were not available for the analysis, the discrepancies found in the data from earlier calibration trials of SCH302 suggest that there may also be uncertainties in the latest calibration trial as well. Such calibration discrepancies may have causing discrepancies in the shape of the frequency response curves. Furthermore the effect of depth on the frequency response of the swimbladdered fish may also be introducing uncertainties. In order to maintain consistency between the SEAT registrations of different vessels, it is necessary to identify all potential problems in the calibration files carefully, and after correction, carry out an alignment based on well ground-truthed fish schools within same spatiotemporal context. The detailed conclusion of this assessment study is as follows.

- The comparison of SIMRAD EK60 and EK80 systems showed significant offsets, which were related to a bug in the software version 1.10.3 of the EK80. After correction the output of both systems was similar. This shows that the mixed application of EK60 and EK80 systems on board SCH06 would not affect species classification;
- The outcome of the comparison of vessel influence could have been more accurate if raw calibration data of the three trawlers would have been available.
- As for frequency response comparison to herring, FV Willem van der Zwan SCH302 and FV Alida SCH6 recordings were consistent while differed from the frequency response of FV Afrika SCH24;
- Of the three 38 kHz channels, the FV Afrika SCH24 produced significantly lower values. The origin could be related to a different transducer type installed, the ES 38-7 transducer (2000 W), having a different hardware architecture from the ES38B (4000 W). Although intended to be equivalent to the ES38B (4000 W) installed on the other two vessels, it has a slightly smaller beam angle and a wider frequency bandwidth.
- There is a slight increase in the response for higher frequency channels (120 kHz, 200 kHz and 333 kHz) to increasing water depth. This depth relationship can be a factor to be taken into account for an improvement in classification;
- As suggested by SIMRAD, the installation of the 1.10.3 version of the EK80 software requires recalibration for all channels for all three vessels. Calibration of FV Afrika SCH24 is urgently needed as data acquired are referred to calibration acquired using the 1.10.0 *beta* release version of the EK80 software;
- Referring present acoustic records with a 1.10.3 release background, containing beam-angle related gain adjustments, to calibration records of previous releases (1.8.2) not containing these adjustments may have had an unknown contribution to the differences found;
- Inter-vessel comparisons can be an effective approach to ensure consistency between vessels and computed frequency responses. A tuning between vessels can be done given the vessels target similar species in close range to each other as performed in the experiment presented in this report. However, ruling out calibration related discrepancies is essential to maintain the aim of a cross-platform classification algorithm. In order to ensure the applicability and reliability of such an approach, further investigation on a larger dataset covering different areas, different fish species, different seasons and different depth ranges is necessary.

4.2 Conclusive discussion & recommendations

Fingerprint analysis of data sets of FV Alida SCH6 (Fassler, 2016) shows that the contribution of the 120 kHz data on the classification of horse mackerel varied with location and increased above latitude 52. In addition, this contribution was much lower for shoals detected in the English Channel. Fassler

(2016) also suggested that water pressure may affect the morphology of swimbladdered species and might explain the variability between shoals detected on the Atlantic Ocean and in the English Channel. A depth related effect was also found in this present comparison study and suggests that water depth has to be encountered as an additional variable for each location. Based on FV Alida SCH6 data, Fassler (2017, Annex II) reported a large overlap coefficient at 120 Hz (91%) and 200 Hz (68%) for herring and horse mackerel schools detected in the English Channel, resulting in major misclassification.

The altering operation of the ES80 software (commercial version of the EK80 system) and the scientific software version EK80 both with different history of version release increased the complexity to an almost unmanageable level. Simplifying to a single more stable software platform, like ES80, as suggested on the PFA meeting of 8 November 2017, may contribute to data management. One of the essential needs for ES80 in scientific applications is the requirement of calibrated references. A calibration GUI is not supported in the ES80 software, but instead the earlier EK500 Bergen Integrator version, with a WMR-built GUI added to it, as used on calibrating ES70 systems for HERAS 6a, could be a suited alternative but will need to be developed for the EK80 system.

4.2.1 Technical issues and data management

The release rate of SIMRAD EK80 software without the opportunities of subsequent calibration trials implies that accurate and strategic management of calibration records is required. Furthermore, in order to prevent calibration related discrepancies, post-processing of calibration records is a necessary prior to the inputting these records to classification procedures. The history of data flow and upgrades of new finger print releases by CMR also needs to be traceable and carefully managed. It should be possible to roll back the system into a previous version in case of unexplained reduced performance of species identification. Software release management is also hampered by the fact, that multiple SIMRAD software tools are operated on freezer trawlers, for commercial fishing practice the SIMRAD E**S**80 software is favourable as it includes filtering to provide smoother images to the skippers. The scientific version software E**K**80 is mainly used on scientific purposes, like SEAT, to have greater control on system settings. Though, both software systems are operating a single WBT transceiver channel, they should produce similar raw data. Altering WBT transceivers between ES and EK80 operation may result in unstable performance. Two software bugs might have affected the calibration references linked to EK80 software releases 1.8.3 and 1.10.3. The EK80 1.8.3. related bug could occur on altering from WB to CW operation, where a wide-band signal was used as 18 kHz CW reference of FV Willem van der Zwan SCH302. This may explain the huge offset in the calibration record of the 18 kHz channel of FV Willem van der Zwan SCH302. From SIMRAD communications, this bug was repaired in the releases after 1.8.3. The second bug was found on assessing the EK80 1.10.3 calibration records used to compare the EK60 and EK80 performance. The background of this bug might have been inconsistency uploading of new calibration result overwriting the previous loaded parameters.

This fishing experiment was executed using SIMRAD release 1.10.3, in which the transceiver gain and beam angle algorithm were modified and recalibration of all transducer channels was addressed in the manufacturer’s release note. As it was practically impossible to recalibrate all three vessels prior to this present experiment calibration data based on older releases notes had to be used. New performed calibration records with this release may further improve the deviation found between vessels.

The SEAT software may have used “invalidated” calibration records, which may have had a significant impact on the overall frequency response. Gain offsets of 1.76 dB minus for 38 kHz and +1.76 dB for 120 kHz would have caused a significant shift in the acoustic fingerprints and in turn in classification performances. The question is if such a correction can be reprocessed at the level of CMR (i.e. algorithm improvement) and if historical data can be rolled back to improve classification.

Although the ship’s staff built up a skill in executing calibrations at sea themselves, occasions to calibrate the echosounder equipment are sparse and depend on the fished area and the distance to near-shore calibration sites. These conditions are more complex for the larger vessels, like FV Willem van der Zwan SCH302, while vessels with smaller fish tank volumes, like FV Alida SCH6, have multiple opportunities on a cruise, provided the fishing area is near-shore.

The SEAT II project encountered also unexpected setbacks. Not all frequency channels could be used in the data of the three vessels. (SCH24 18 kHz, SCH6 333 kHz, SCH302 120 kHz). In 2016 the participation of FV Afrika SCH24 was delayed due to adjustment of the transceiver installation to reduce overall electric interferences. The 120 Hz transducer channel on board FV Willem van der Zwan SCH302 was disabled due to a faulty cable configuration for about half a year. In addition, FV Afrika SCH24 and FV Alida SCH6 left EU waters to target sardine or horse mackerel in African waters. This all points out the need to extend to a fourth vessel, such as FV Frank Bonefaas SCH72 or smaller vessels, such as FV Prins Bernard FC 716 900 or the new build 80 m trawler of Cornelis Vrolijk BV. (to be expected in December 2018).

Acknowledgement

We are grateful to our colleague Dr. Benoît Bergès for not only reviewing this report independently but also contributed to the improvement of the quality and content of the text through his constructive comments .

5 Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2008 certified quality management system (certificate number: 187378-2015-AQ-NLD-RvA). This certificate is valid until 15 September 2018. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V.

Furthermore, the chemical laboratory at IJmuiden has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 1th of April 2021 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation. The chemical laboratory at IJmuiden has thus demonstrated its ability to provide valid results according a technically competent manner and to work according to the ISO 17025 standard. The scope (L097) of de accredited analytical methods can be found at the website of the Council for Accreditation (www.rva.nl).

On the basis of this accreditation, the quality characteristic Q is awarded to the results of those components which are incorporated in the scope, provided they comply with all quality requirements. The quality characteristic Q is stated in the tables with the results. If, the quality characteristic Q is not mentioned, the reason why is explained.

The quality of the test methods is ensured in various ways. The accuracy of the analysis is regularly assessed by participation in inter-laboratory performance studies including those organized by QUASIMEME. If no inter-laboratory study is available, a second-level control is performed. In addition, a first-level control is performed for each series of measurements.
In addition to the line controls the following general quality controls are carried out:

- Blank research.
- Recovery.
- Internal standard
- Injection standard.
- Sensitivity.

The above controls are described in Wageningen Marine Research working instruction ISW 2.10.2.105. If desired, information regarding the performance characteristics of the analytical methods is available at the chemical laboratory at IJmuiden.

If the quality cannot be guaranteed, appropriate measures are taken.

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Justification

Report: Evaluation of the SEAT II joint-industry project
Project Number: 4311100022

The scientific quality of this report has been peer reviewed by a colleague scientist and a member of the Management Team of Wageningen Marine Research

Approved: Benoit Berges

Signature:

Date: date

Approved: name Management team member being responsible for the scientific content of this report
function

Signature:

Date: date

Annex I Investigation of the acoustic finger print (frequency response) variation of horse mackerel

Author: Dr. Sasha Fassler, 13 September 2016

Data

Acoustic multifrequency data of horse mackerel were collected at 18, 38, 70, 120, and 200 kHz by SCH6 (Alida) during several fishing trips between 27.04.2015 and 16.02.2016. The available dataset consisted of calibrated volume backscatter values of trawl-identified horse mackerel schools. The acoustic data were integrated and converted to relative frequency response values per school cells (5m x 0.01nm).

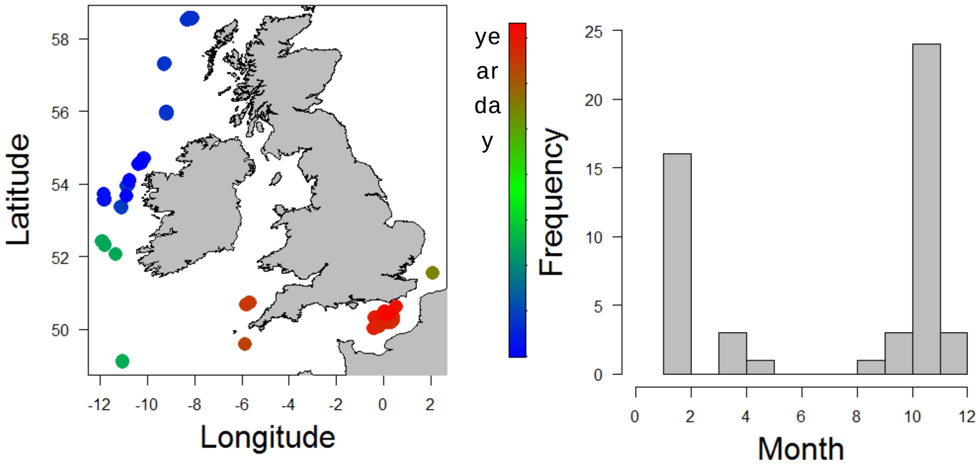

Figure 1. *Left panel: map with locations of available horse mackerel multi-frequency acoustic data including date of the trawl indicated by colours (blue/day 1 = 1st January; red/day 365 = 31st December). Right panel: number of horse mackerel schools available per calendar month from the data set.*

Note: The available data were chosen subjectively by the data managers and therefore do not represent a random sample of the truth. Any analysis results can therefore not be interpreted as a reflection of reality but are purely linked to the available data set, to give an indication of observed patterns in the selected data.

Number of schools available from the data is not uniform over the time period and distinct localised clusters were visible (see ***Figure 1***). The data set is imbalanced with most school data records coming from February and November. Horse mackerel schools caught at the western shelf were well spread over the observed latitudinal range, however, schools observed in the Celtic Sea and English Channel were more sporadic and clustered at distinct times and locations.

Some of the variables extracted from the horse mackerel school data were, not surprisingly, correlated. In general, catches at higher latitudes happened early in the year, at deeper depths and of larger schools. School sizes were also more variable and generally larger towards the west and earlier in the year (see ***Figure 2***).

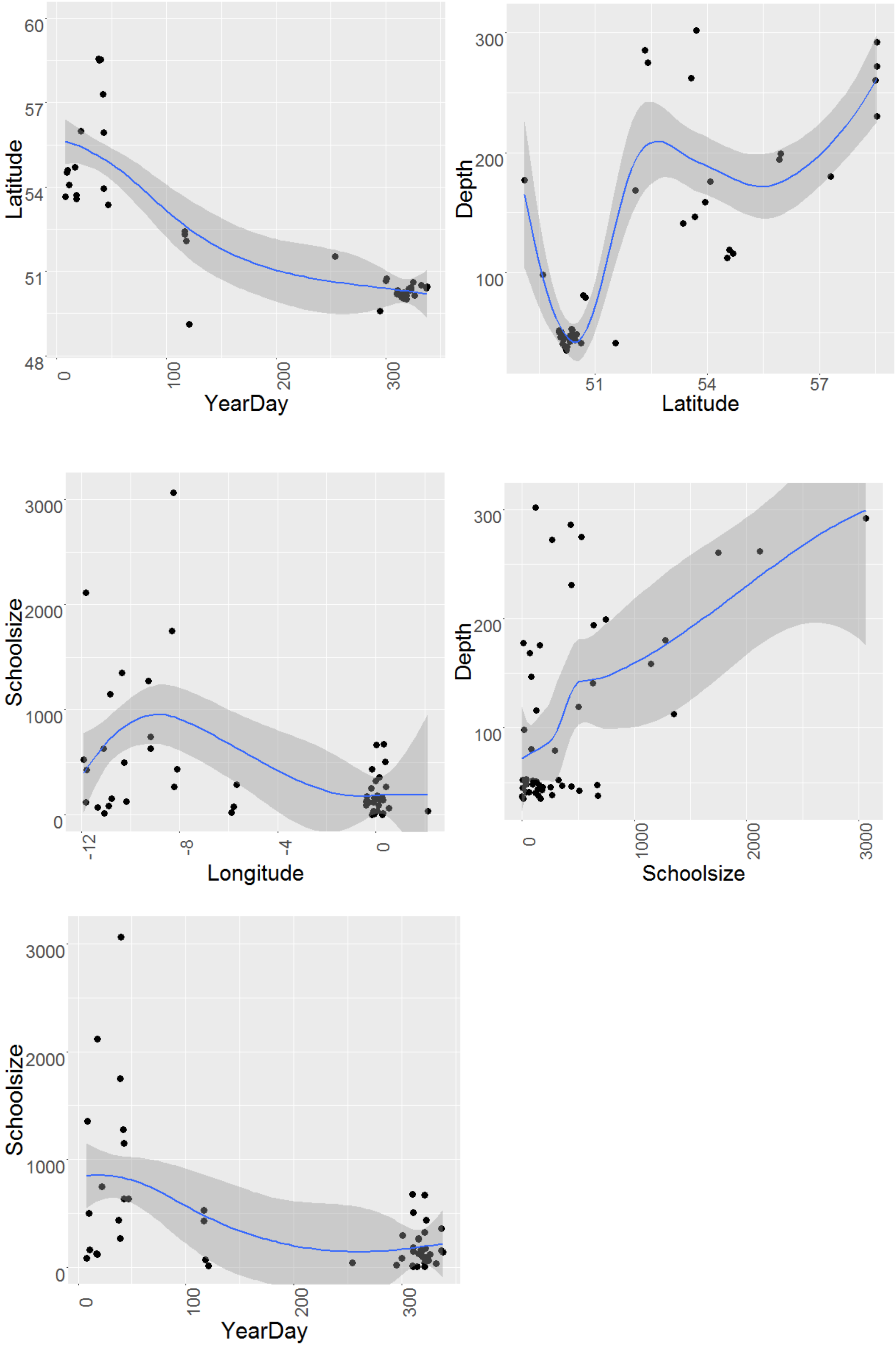

Figure 2: *Relationships between horse mackerel school data covariates.*

Analysis

Generalised additive models (GAM) were used to interpret the observed pattern in the data and to make model predictions.

relative frequency at 120 kHz

The relative frequency response at 120 kHz (=r (120)) has been found to be indicative for the horse mackerel acoustic signature and therefore an important factor in its successful identification.

In a first attempt, a GAM was used to predict r (120) of the observed horse mackerel schools from the following variables: latitude, longitude, school depth, bottom depth, year day, month, school size. An iterative boosting algorithm was applied to determine an appropriate number of boosting iterations based on the Akaike information criterion (AIC). The results indicated that latitude, school size and year day enter the most optimal model. However, as year day is a linear function of latitude in this case, it was decided to refrain from using that covariate. The partial contributions of each covariate to the predicted r (120) value are given in ***Figure 3***. Subsequently, due to their spatial definition, both latitude and longitude were included in the model as an interaction term. The residual plot showed no obvious patterns (***Figure 3***).

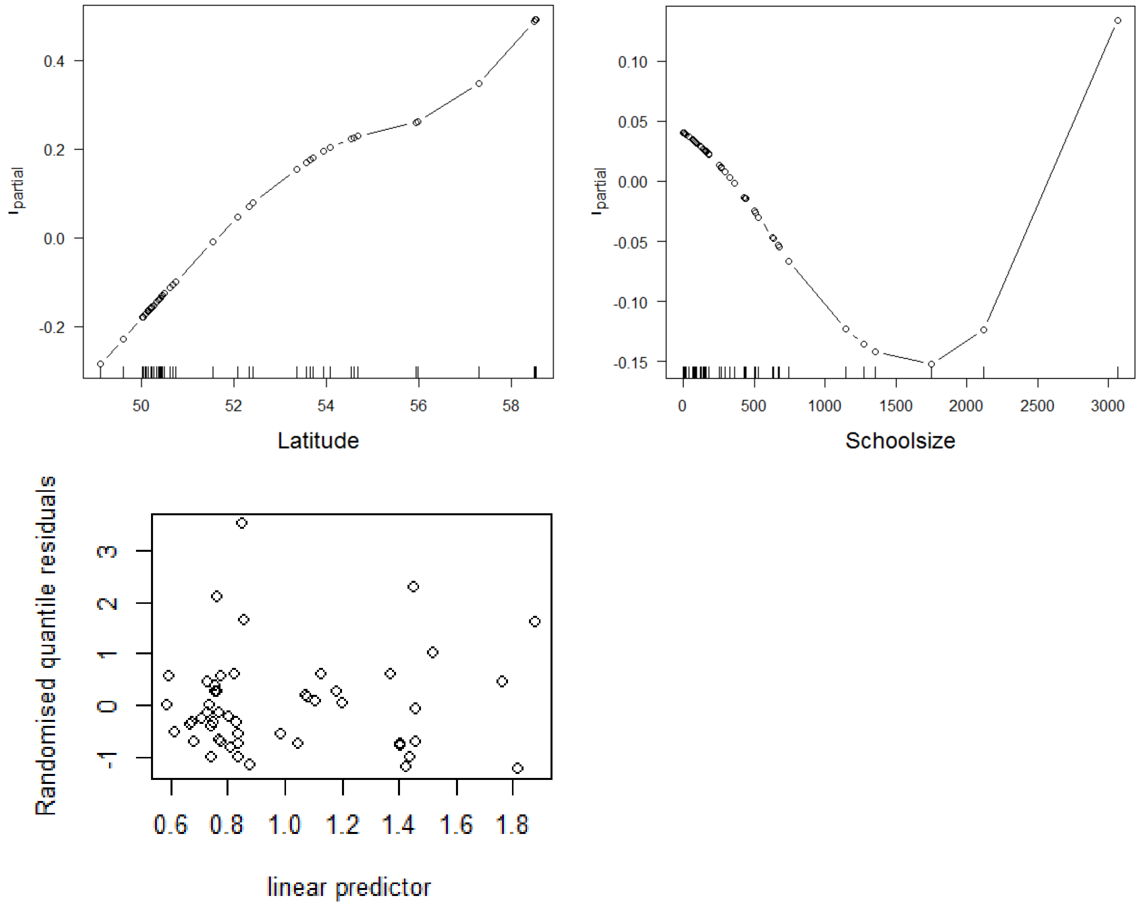

Figure 3*. Top panels: Partial contributions of exploratory covariates to the predicted r (120) value in the GAM. Bottom panel: Residual versus linear prediction plot of r (120) values.*

The partial contributions of each covariate to the predicted r (120) are shown in ***Figure 4***. Based on the partial smoother contributions it is evident that in the available data, r (120) values are predicted to become larger at locations towards the north-west and the values are more variable with larger school sizes.

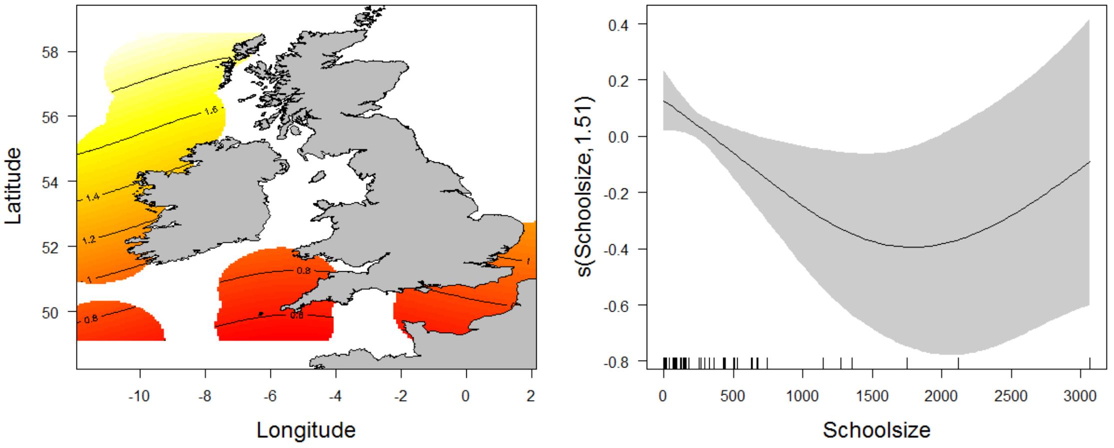

Figure 4. *Partial contributions of exploratory variables.*

Peak at 120 kHz

Based on historical data collected primarily in the north of the observed distribution area, a feature thought characteristic of the horse mackerel relative frequency response is the presence of a peak at 120 kHz.

In order to investigate that feature in the present data set, an additional binomial variable was created to indicate “r (120) peak”, if r (120)>[r (70) AND r (200)]. “no r (120) peak” was defined by the condition r (120)<[r (70) AND r (200)]. ***Figure 5*** shows that horse mackerel schools in the available data set have a higher chance for “r (120) peak” at higher latitudes, lower longitudes, at larger school sizes, and when caught early in the year.

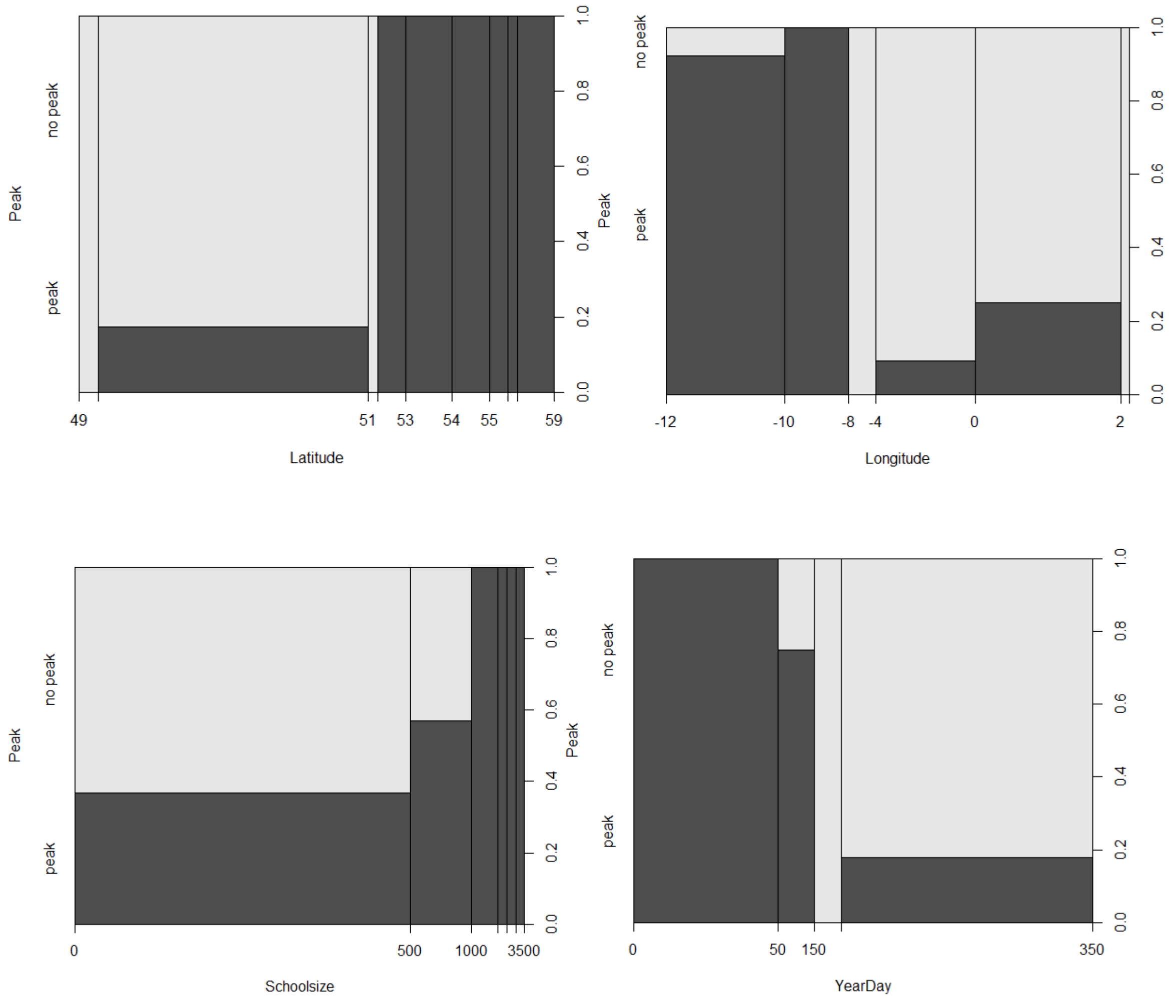

Figure 5. *Spinograms of the four exploratory variables and response variable “r (120) peak”.*

A GAM was used to predict the presence of a r (120) peak from the data based on latitude and longitude information. School size was excluded this time as it did not contribute substantially to the explained deviance of the model. ***Figure 6*** shows the spatial prediction of the probability to encounter a horse mackerel school with a peak at 120 kHz. The chances for a peak at 120 kHz being present in the data decreased towards locations in the English Channel. At latitudes above 52°N, only schools with a peak at 120 kHz were encountered, while only very few schools in the English Channel had such a peak.

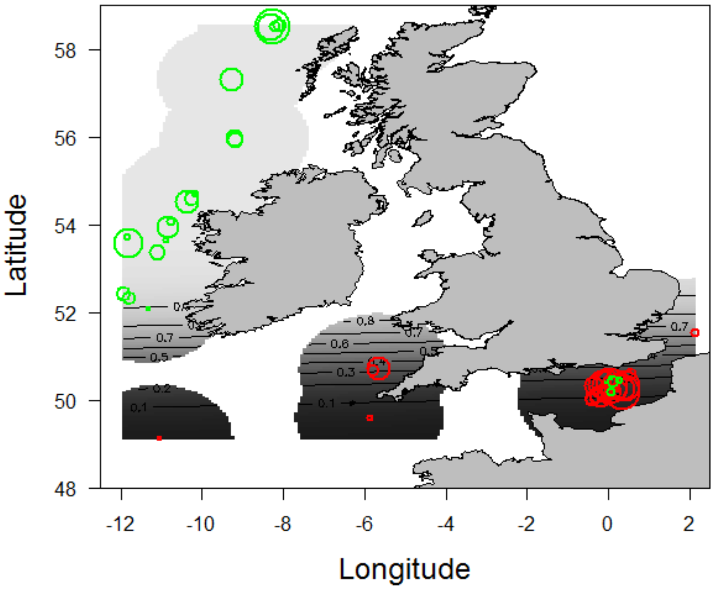

Figure 6: *Spatial prediction of the chance to encounter "r (120) peak" in horse mackerel schools. Underlying school data are superimposed by bubbles (radius = school size; colour = "r (120) peak" (green) or "no r (120) peak" (red)).*

Another exploratory GAM was used to predict catch location as a function of day of the year (see ***Figure 7***). Catches at north-western locations in the available data set were done earlier in the year. This coincides with encountering schools that predominantly exhibit a 120 kHz frequency response peak.

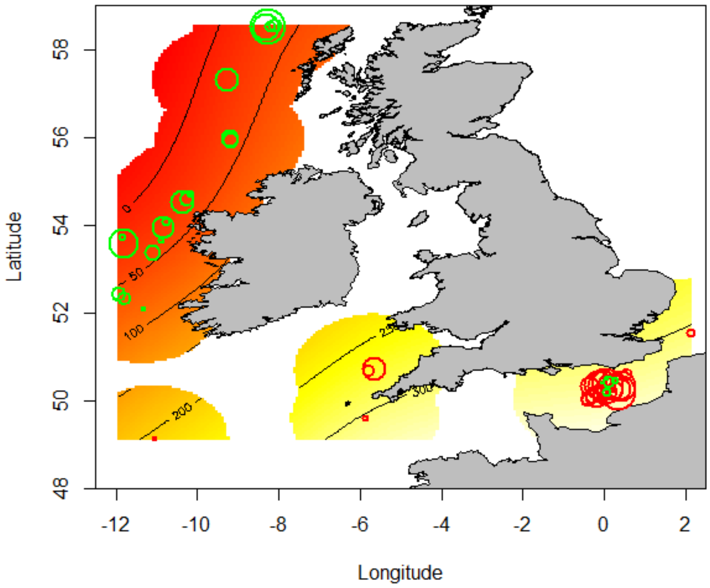

Figure 7: *Spatial prediction of the day of the year of encountered horse mackerel schools. Underlying school data are superimposed by bubbles (radius = school size; colour = "r (120) peak" (green) or "no r (120) peak" (red)).*

Spatial prediction of the horse mackerel relative frequency response

Finally, GAMs were used to predict the observed mean r (f) values of the horse mackerel school as a function of school location. The mean relative response per horse mackerel school of each available frequency, other than the reference frequency 38 kHz, was modelled individually.

While r (18) and r (70) were observed to generally increase towards locations towards the east in the English channel, r (120) and r (200) showed increasing values towards northern locations (***Figure 8***).

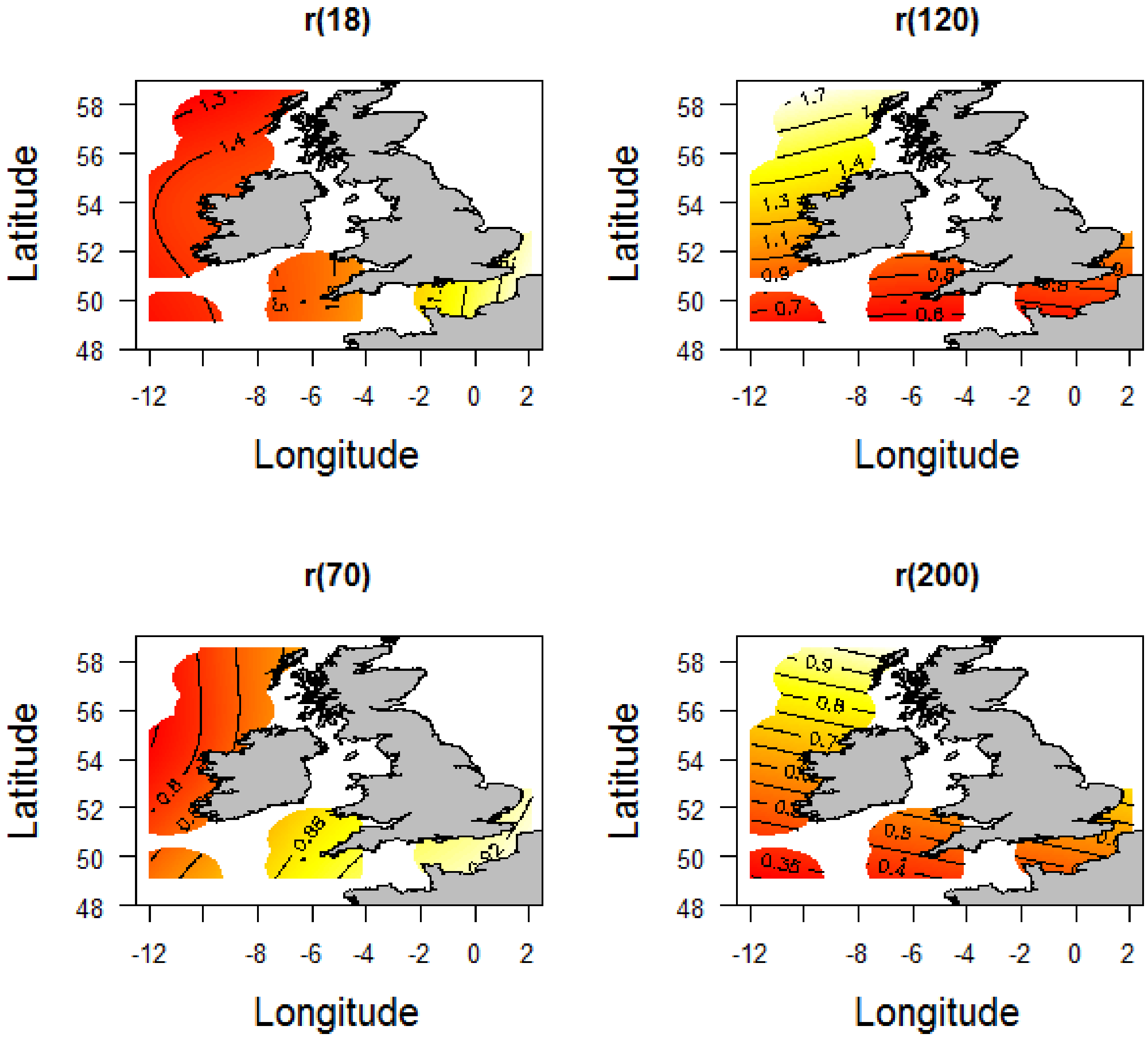

Figure 8: *Spatial prediction of the relative frequency response of horse mackerel schools (red=smaller; yellow=larger).*

The output of the different models were combined for exploratory indicative predictions (due to the limited data set) of the frequency response based on the observed data (Figure 9). Peaks at 120 kHz were modelled to be present at locations west of Britain and Ireland, however, the peak feature becomes weaker when moving towards the south. When moving towards the English Channel, the peak feature disappears completely and the response is more similar to a general “swimbladdered fish” pattern with an increased r (f) at 18 kHz as well.

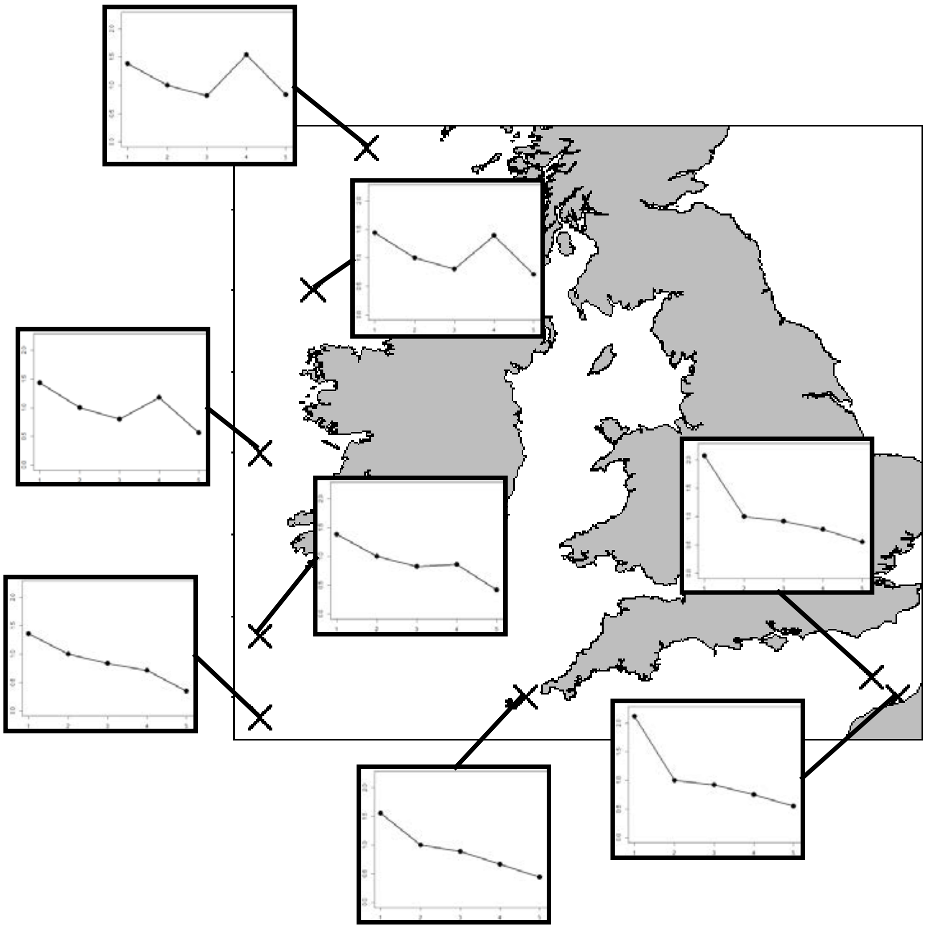

Figure 9: *Model predictions of the relative frequency response of horse mackerel schools at arbitrary locations within the encountered spatial range.*

Summary & Conclusions

- The available data set consisted of a subjective pick of horse mackerel schools. Any drawn conclusions from analyses of these data can therefore not be interpreted as a reflection of reality and are purely indicative.
- The majority of observed horse mackerel school data came from February and November recordings. Schools observed at the western shelf were spread over the latitudinal range, while those observed in the Celtic Sea and English Channel appeared more sporadic and clustered.
- In general, catches at higher latitudes were done early in the year, at deeper depths and over larger schools. School sizes were also more variable and generally larger towards the west and earlier in the year.
- Model predicted r ($f_{120\ \text{kHz}}$) values from the available data set increase at locations towards the north-west and the values are more variable with larger school sizes.
- Observed horse mackerel schools had a higher chance of showing a peak at 120 kHz when they were: (1) located at higher latitudes; (2) located towards the west; (3) made of larger school sizes, (3) caught early in the year. Schools with a peak at 120 kHz were only encountered in the data set at latitudes above 52°N, while only very few schools in the English Channel had such a peak.
- Reasons for the variation in frequency responses observed could be related to morphological differences of the encountered fish, their fat content, behaviour, or size. Equally, due to differences observed in water depths, depth-dependent

swimbladder compression could have an effect on the frequency response. Mixture with other species could also be a reason, however, most of the examined data stem from almost clean horse mackerel catches.

further work

- As a next step, it is suggested to **repeat the analysis with a bigger and more representative dataset**. That would require inclusion of all suitable horse mackerel acoustic data collected so far (and in the future).
- Models based on a representative dataset could then be used to **predict horse mackerel frequency responses** based on school location and possible other variables (date, depth, school size, etc). These results could then be used within SEAT to improve classification.

Annex II Investigation of the acoustic finger print (frequency response) differences between herring and horse mackerel in the English Channel and outside

Author: Dr. Sasha Fassler, 11 January 2017

Data

Acoustic multifrequency data of herring and horse mackerel were collected at 18, 38, 70, 120, and 200 kHz by SCH6 (Alida) during several fishing trips between 27.04.2015 and 16.02.2016. The available dataset consisted of available calibrated volume backscatter values (S_v) of trawl-identified single-species schools of these species. The acoustic data were integrated and converted to relative frequency response (reference 38 kHz) values per school cells (5m x 0.1nm).

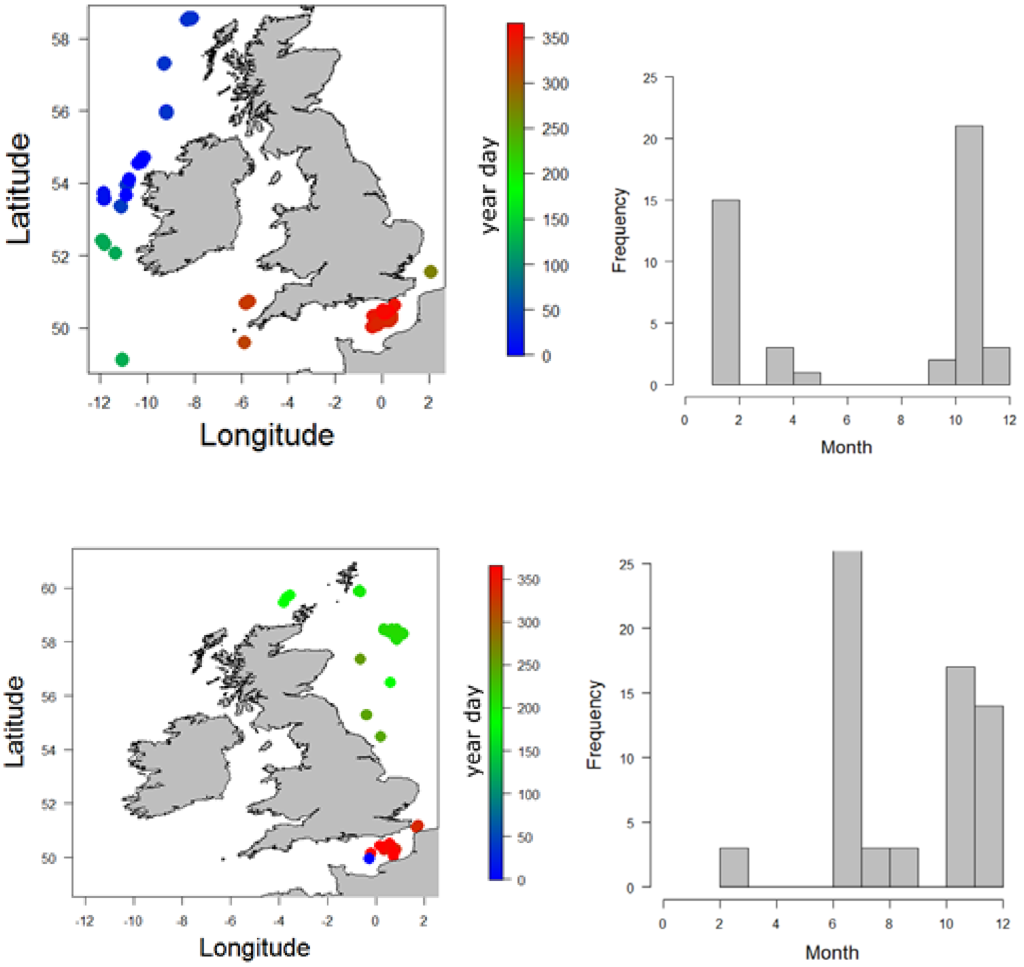

Figure 1. *Left panel: map with locations of available horse mackerel (top) and herring (bottom) multifrequency acoustic data including date of the trawl indicated by colours (blue/day 1 = 1st January; red/day 365 = 31st December). Right panel: number of horse mackerel (top) and herring (bottom) schools available per calendar month from the data set.*

Note: The available data do not represent a random sample of all available cases but represent a (limited) set of available schools linked to single-species catches. Any analysis results do therefore bring a degree of bias and are purely linked to the available data set, to give an indication of patterns in the observed data.

Several schools available from the data were not uniform over the time period. As a result, distinct localised clusters could be observed (see ***Figure 1***). The data set is imbalanced with most school data records coming from February and November (horse mackerel) or June and November/December (herring). Horse mackerel schools caught at the western shelf and herring schools caught in the North Sea were well spread over the observed spatial range, however, schools observed in the English Channel were more sporadic and clustered at distinct times and locations.

For correlations between observed horse mackerel school variables, see previous report titled (Annex I, Fassler, 2016).

Some of the variables extracted from the herring school data were, similarly as for horse mackerel, correlated. In general, catches at higher latitudes happened in the middle of the year. Compared to horse mackerel, there was less observed variation in herring school size with either latitude and time of the year. (see ***Figure 2***).

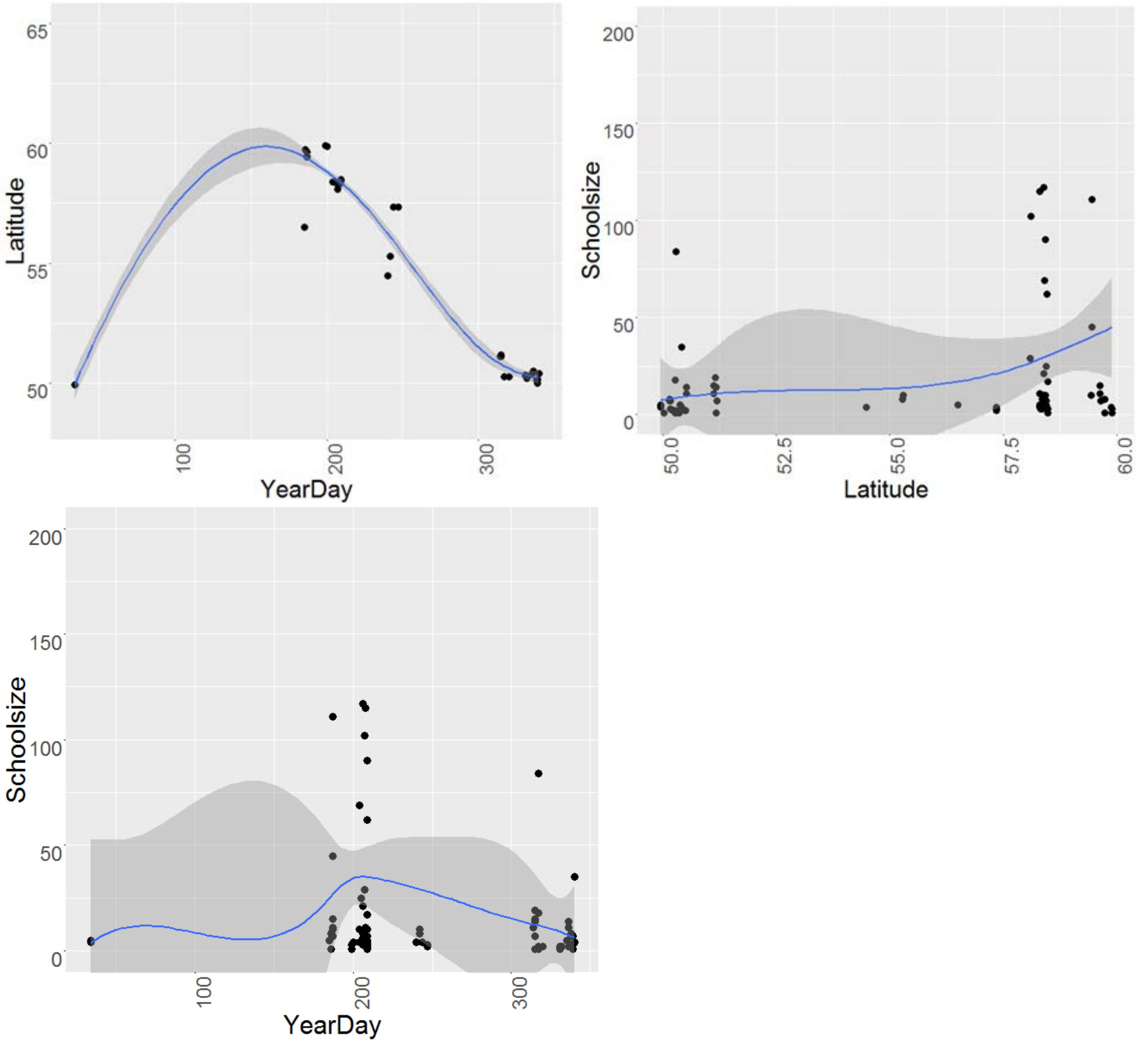

Figure 2: *Relationships between herring school data covariates.*

Analysis

Differences in log-transformed relative frequency responses at the observed frequencies (r (f)) were analysed between herring and horse mackerel, both in the English Channel and outside. Predictions of r (f) values were made using Generalised Additive Models (GAM).

In fassler 2016 (Annex I), it was shown that model predicted r ($f_{120\ \text{kHz}}$) values for horse mackerel increased at locations towards the north-west and the values are more variable with larger school sizes. Also, observed horse mackerel schools had a higher chance for showing a peak at 120 kHz, an indicative feature for horse mackerel, when they were at higher latitudes, towards the west, at larger school sizes, and when caught early in the year. Schools with a peak at 120 kHz were only encountered in the data set at latitudes above 52ºN, while only very few schools in the English Channel had such a peak. Therefore, it is of interest to determine if the horse mackerel schools in the English Channel show a similar frequency response there as herring and are therefore difficult to distinguish from herring them with multifrequency techniques.

An exploratory GAM was used to predict catch location as a function of day of the year (see ***Figure 3***). Catches of horse mackerel at north-western locations in the available data set were done earlier in the year, while those done later in the year coincided with catches of herring in the eastern English Channel.

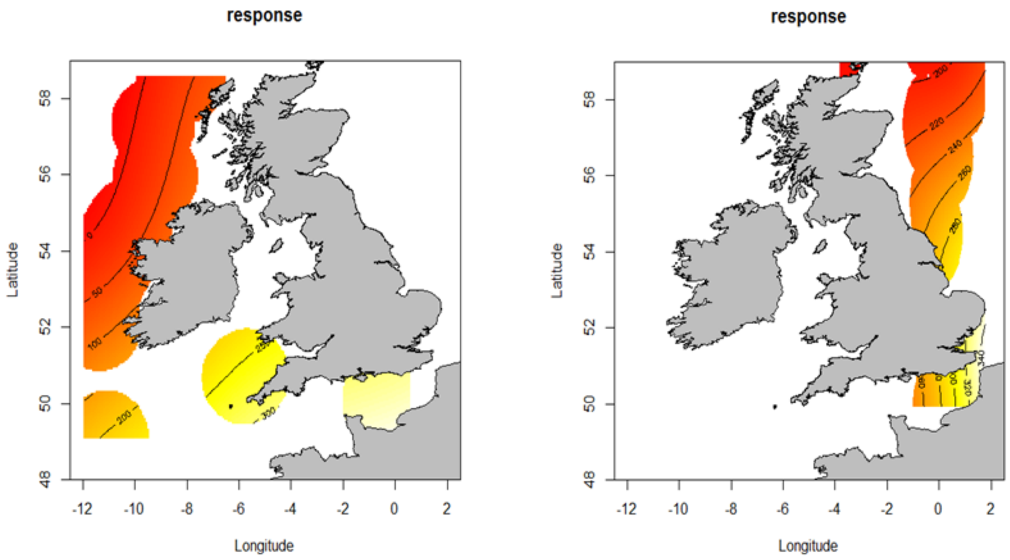

Figure 3: *Spatial prediction of the day of the year of encountered horse mackerel (left) and herring (right) schools.*

Spatial prediction of the herring relative frequency response

For spatial predictions of the horse mackerel relative frequency response see fassler 2016 (Annex I). GAMs were used to predict the observed mean r (f) values of the herring schools as a function of school location. The mean relative response per herring school of each available frequency, other than the reference frequency 38 kHz, was modelled individually.

While r (18), r (120), and r (200) were observed to generally decrease towards locations in the north in the North Sea, r (70) showed increasing values towards both the north and the English Channel with a minimum at locations in the western and southern North Sea (***Figure 4***).

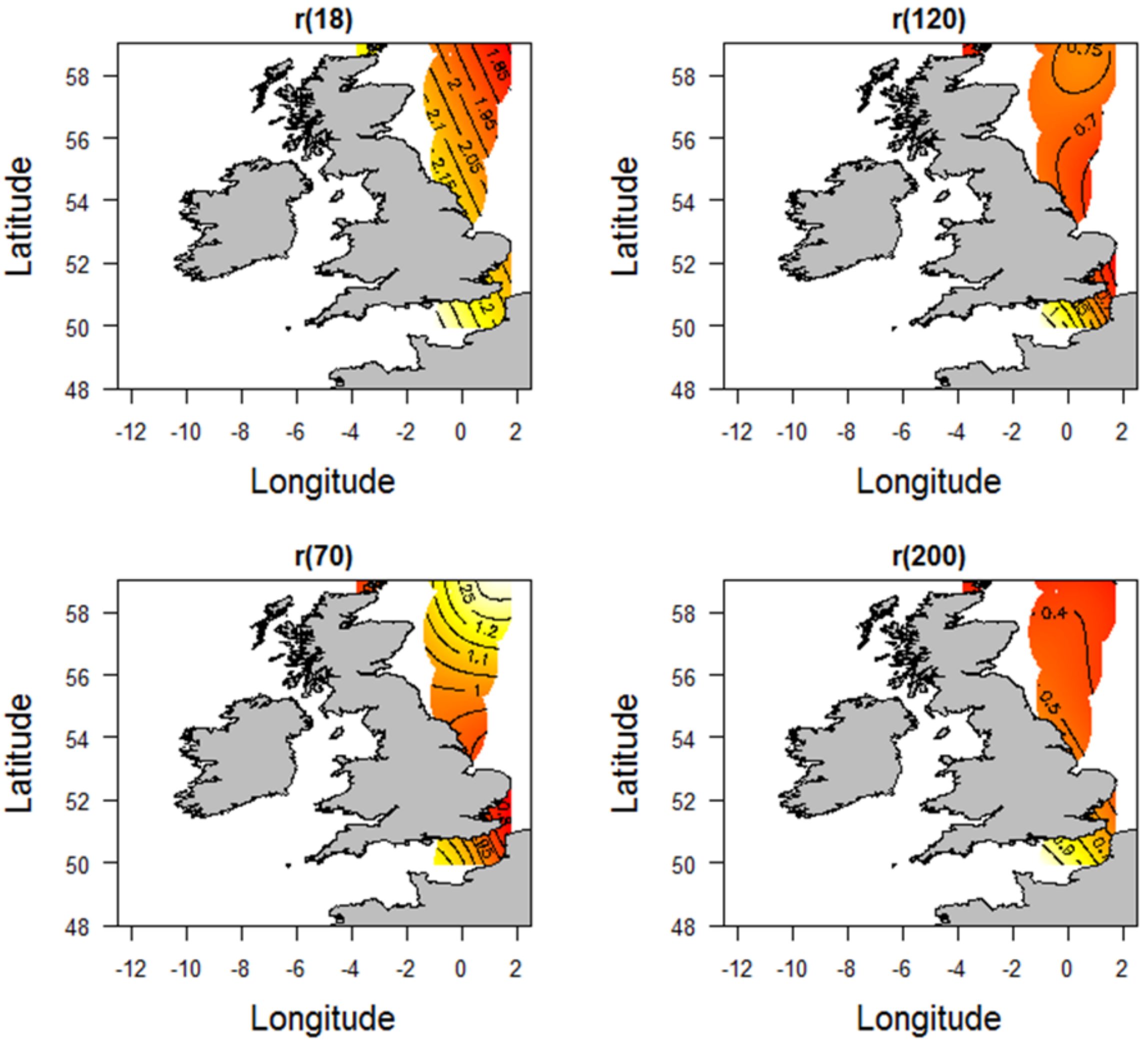

Figure 4: *Spatial prediction of the relative frequency response of herring schools (red=smaller; yellow=larger).*

Spatial differences in observed r (f) between herring and horse mackerel

The log-transformed r (f) values of the observed horse mackerel and herring schools were split into three area groups (west coast, Channel, and North Sea) and compared between the species. Area west coast (for horse mackerel only) was defined as west of 6°W, and

North Sea (for herring only) as north of 52°N. There were no herring in the “west coast” group and conversely no horse mackerel in the “North Sea” group.

The observed log-transformed r (f) values showed clear differences between the species at frequencies >38 kHz in areas outside the English Channel. However, for schools observed inside the English Channel, r (f) values were more similar with the largest difference seen at 200 kHz (***Figure 5***).

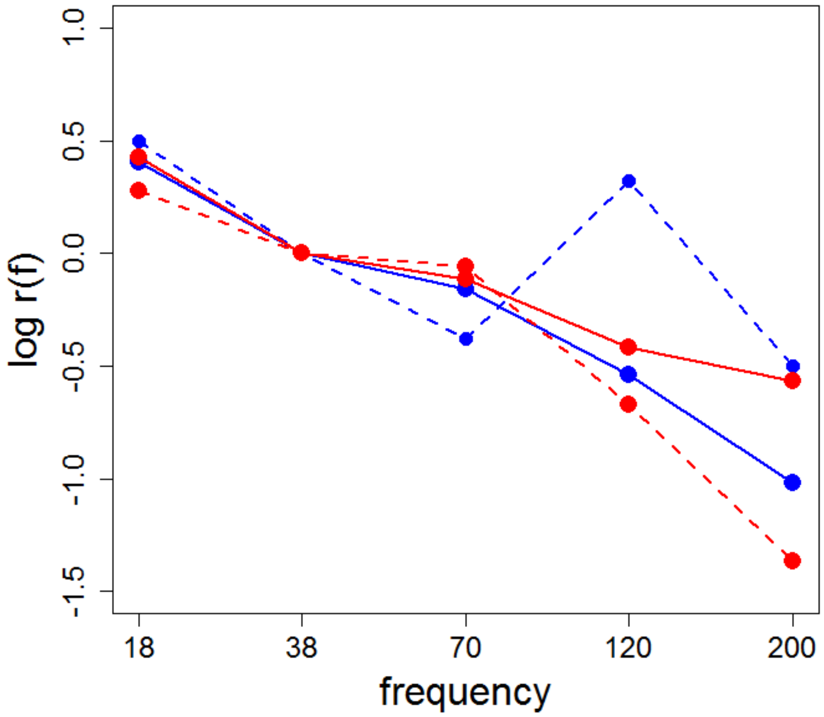

Figure 5: *Observed log-transformed mean relative frequency responses of horse mackerel (blue) and herring (red) in the English Channel (solid lines) and outside (dashed lines: west coast for horse mackerel, and North Sea for herring).*

When only looking at the r (f) mean and variance of schools of the two species observed in the English Channel, it is apparent that any differences at frequencies of 18 and 70 kHz are not significant while those at 120 kHz are but with a low significance level (p=0.006). These differences are probably not enough for successful classification in practise. The largest significant differences are observed between r (f) values at 200 kHz (p<0.001) (***Figure 6***).

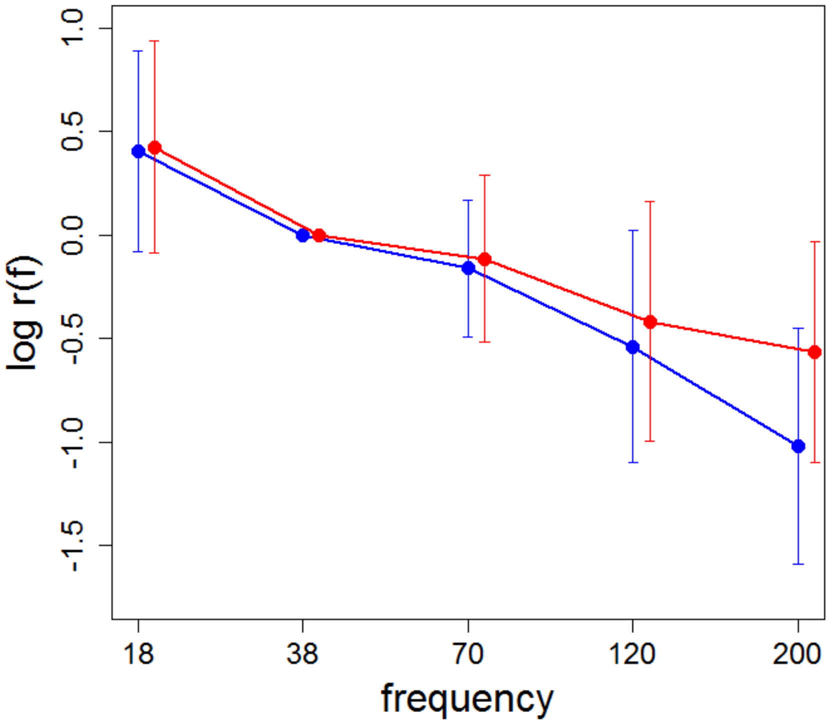

Figure 6: *Observed log-transformed mean (dots) and standard deviation (bars) of relative frequency responses of horse mackerel (blue) and herring (red) in the English Channel. Values for herring have a slight offset on the x-axis to ease comparison.*

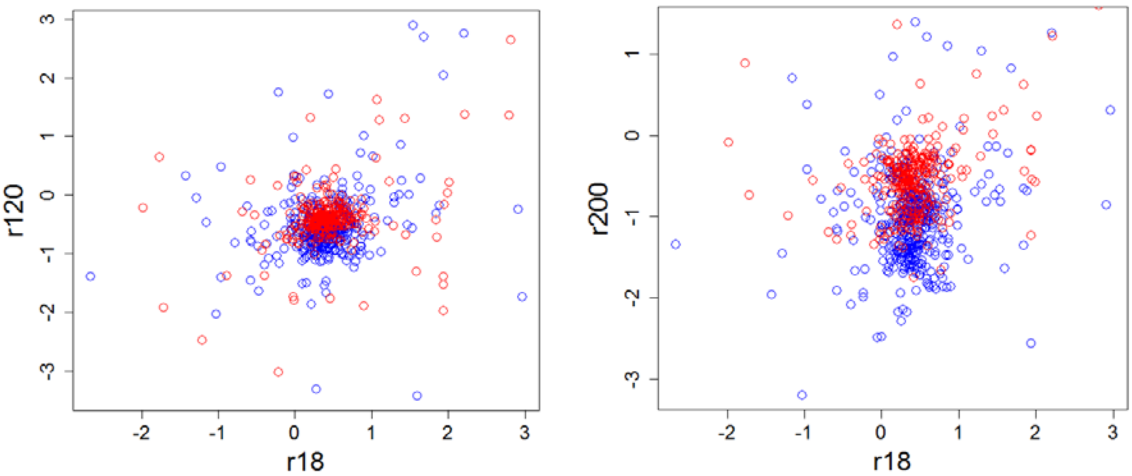

Figure 7: *Point cloud of log-transformed r (f) values for herring (red) and horse mackerel (blue) using the r (f=120 kHz) (left) and r (f=200 kHz) (right) as a discriminator. R (18) was used as a reference in both cases.*

Figure 7 shows the respective point clouds that indicate the potentially better discriminant features in the English Channel when using the relative frequency response at 200 kHz compared to the one at 120 kHz, which is usually characteristic for horse mackerel.

In order to be practically useful, any differences observed at individual frequencies would have to be large enough to prevent misclassification. In both of the most promising cases where there are more distinct differences in r (f) between herring and horse mackerel schools in the English Channel, at 120 and 200 kHz, there is still a large overlap. The ‘overlapping coefficient’ of the density curves, which describe the spread of values around the observed mean r (f) for herring and horse mackerel, is considerable (91% for r (f=120); and 68% for r (f=200)) (see ***Figure 8***).

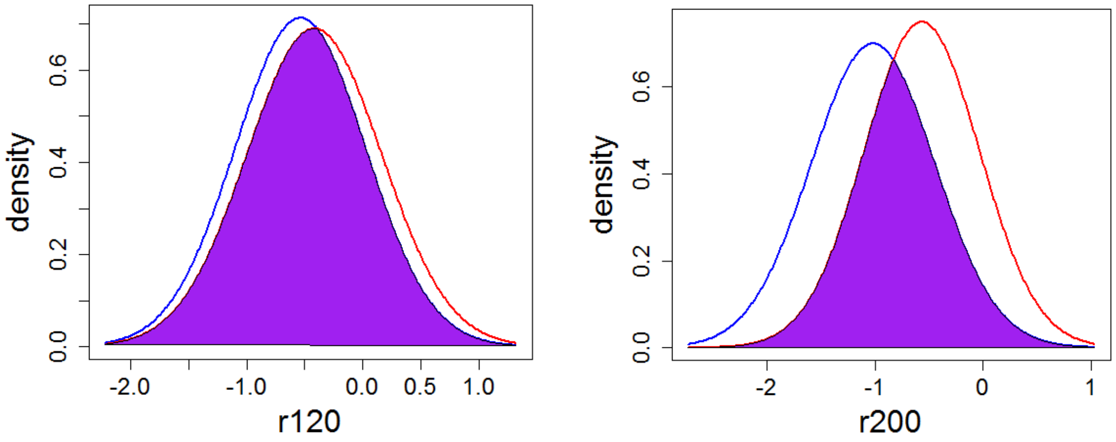

Figure 8. *Probability density functions fitted to the observed relative frequency values at 120 kHz (left panel) and 200 kHz (right panel) for herring (red curves) and horse mackerel (blue curves). The overlapping area covered by both curves is indicated in purple colour.*

Summary & Conclusions

- The majority of observed horse mackerel school data came from February and November recordings, while most of the herring data stem from June, November and December. Horse mackerel schools observed at the western shelf and herring schools in the North Sea were spread over the latitudinal range, while those observed in the English Channel for both species appeared more sporadic and clustered.

- In general, herring catches at higher latitudes were done in the middle of the year and those in the English Channel at the end of the year. School sizes were less variable and comparable between seasons.
- Model predicted r (f) values for herring showed that r (18), r (120), and r (200) generally decreased towards locations in the northern North Sea, while r (70) showed increasing values towards both the north and the English Channel.
- Observed r (f) values showed clear differences between herring and horse mackerel at frequencies >38 kHz in areas outside the English Channel.
- Herring and horse mackerel schools observed inside the English Channel had r (f) values that were more similar to each other. The biggest differences there were seen at 200 kHz.
- At frequencies where most of the differences occurred, in r (f) between herring and horse mackerel schools in the English Channel, at 120 and 200 kHz, there is still a large overlap of values. The ‘overlapping coefficient’ of the density curves is considerable in both cases, still resulting in major misclassification (91% and 68% respectively).
- Reasons for the variation in frequency responses observed between areas in the English Channel and outside could be related to morphological differences of the encountered fish, their fat content, behaviour, or size. Equally, due to differences observed in water depths between the English Channel and areas outside, depth-dependent swimbladdered compression could have an effect on the frequency response.
- Based on the observations and data set described here, it can be concluded that multifrequency distinction between herring and horse mackerel schools co-occurring in the English Channel remains challenging if not impossible in practise.

further work

- As a next step, it is suggested to **repeat the analysis with a bigger and more representative dataset once these become available (over time or from other ships)** to confirm the observations and derive best possible discriminant features.
- Models based on a representative dataset could be used to **predict most likely horse mackerel or herring frequency responses** based on school location and possible other variables (date, depth, school size, etc.). These results could then be used within SEAT to potentially improve classification. Alternatively, an empirical approach could be used where different species libraries are applied based on data from different areas/times.

Annex III Comparison between SIMRAD EK60 and EK80 performance

To check the consistency between the EK60 and the EK80 systems, data collected by FRV Tridens II in July 2017 during the HERAS survey was used. On FRV Tridens, both the EK60 and the EK80 transceivers can be operated in alternating mode to drive the same hull-mounted transducers (18 kHz, 38 kHz, 70 kHz, 120 kHz, 200 kHz and 333 kHz) in a ping to ping sequence using the K-Sync Kongsberg system. This enables the acquisition of acoustic data for both the EK60 and the EK80 at few milliseconds intervals, i.e. almost simultaneous having both systems virtually ensonifying the same sample volume. Such a setup gives the best possible comparison between the two SIMRAD systems. The data set consists of records of 5 hours of recording at 6 frequencies of 3 different days.

An initial assessment of the HERAS 2017 data set showed a significant acoustic intensity level offset for the 38 kHz channel between the two systems. Following this finding, historical records for the EK80 on RFV Tridens 2 was investigated. This included calibration records for the Blue Whiting and HERAS surveys conducted in 2016 and 2017.

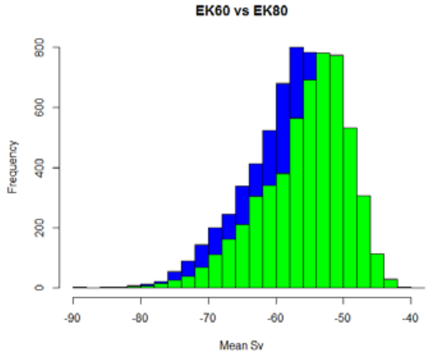

Figure III.1: *comparison of frequency distribution of echo-levels (S_v) for the 38 kHz channel between EK60 (blue bars) and EK80 (green bars). A significant offset can be observed at 38 kHz because of an erroneous calibration parameter.*

The gain values presented here and further in this report are the S_v gains. This quantity is the combination of TS gain and Sa correction as used for calculation of S_v levels (ICES, 2015). It is important to note that it should not be confused with the TS gain.

The S_v gains computed from raw data (using Echoview) and the EK80 software are showed in Figure III.2. It can be observed that while raw data show consistent gain levels through the years (dashed red line), the calibration performed using the EK80 software (straight black line) exemplifies a suspicious oscillation around the gain inferred from direct analysis of the raw data. The results from this raw data analysis together with scrutiny of the EK80 software results showed that the fluctuations are due to a bug in the software (see Section 3.2.1.). The resulting error from this software was as high as of 1.76 dB in Sa correction. Sa corrections are typically within 0.5 dB of factory default values. Such an offset severely impacts Sv levels and in turn the ability of the system to give comparable results between different echo-sounders.

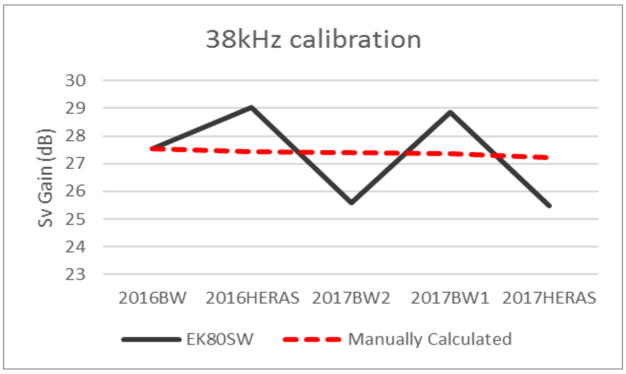

Figure III.2: *Sv calibration results computed from the EK80 software (solid black line) and from raw data using Echoview (dashed red line). The data refers to the 38 kHz channel for the calibration trials performed during the herring (HERAS) & Blue Whiting (BW) surveys in 2016 and 2017. The solid black line represents the erroneous calculations using the EK80 software.*

Using the corrected S_v gain, the EK60/EK80 ping to ping analysis was reiterated. The resulting S_v distribution is shown in Figure III.3. It can be observed that the initial offset (Figure III.1) is now corrected. As for the other channels, there is a very good correlation between the measurements from the EK60 and the EK80. ***Figure 4*** shows the outputted echogram after correction of the calibration data, exemplifying very similar colour distribution. Table III.1 shows the summary of the results, with a NASC (*Nautical Area Scattering Coefficient*) that is similar for both the EK60 and the EK80. This is suggesting that results from these systems are very comparable and can be cross-compared.

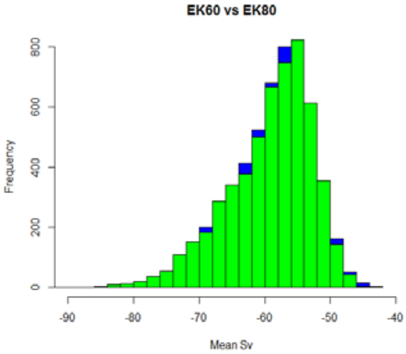

Figure III.3: *comparison of frequency distribution of echo-levels (S_v) for the 38 kHz channel between EK60 (blue bars) and EK80 (green bars). The initial use of an erroneous calibration parameter (Figure III.1) has been accounted for.*

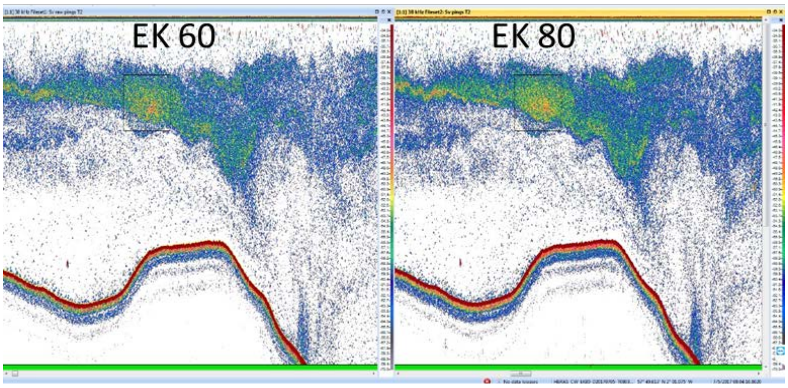

Figure III.4: *Ping to ping near-simultaneous registrations by EK 60 and EK80 with corrected calibration settings.*

Wageningen Marine Research
T +31 (0)317 48 09 00
E: marine-research@wur.nl
www.wur.eu/marine-research

Visitors' address
- Ankerpark 27 1781 AG Den Helder
- Korringaweg 5, 4401 NT Yerseke
- Haringkade 1, 1976 CP IJmuiden

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- To conduct research with the aim of acquiring knowledge and offering advice on the sustainable management and use of marine and coastal areas.
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