Research Cruise Report [2020823]: Catch-control and fish-welfare in the Norwegian mackerel purse seine fishery.

M/S «Fiskebas» 21. September – 04. October 2020

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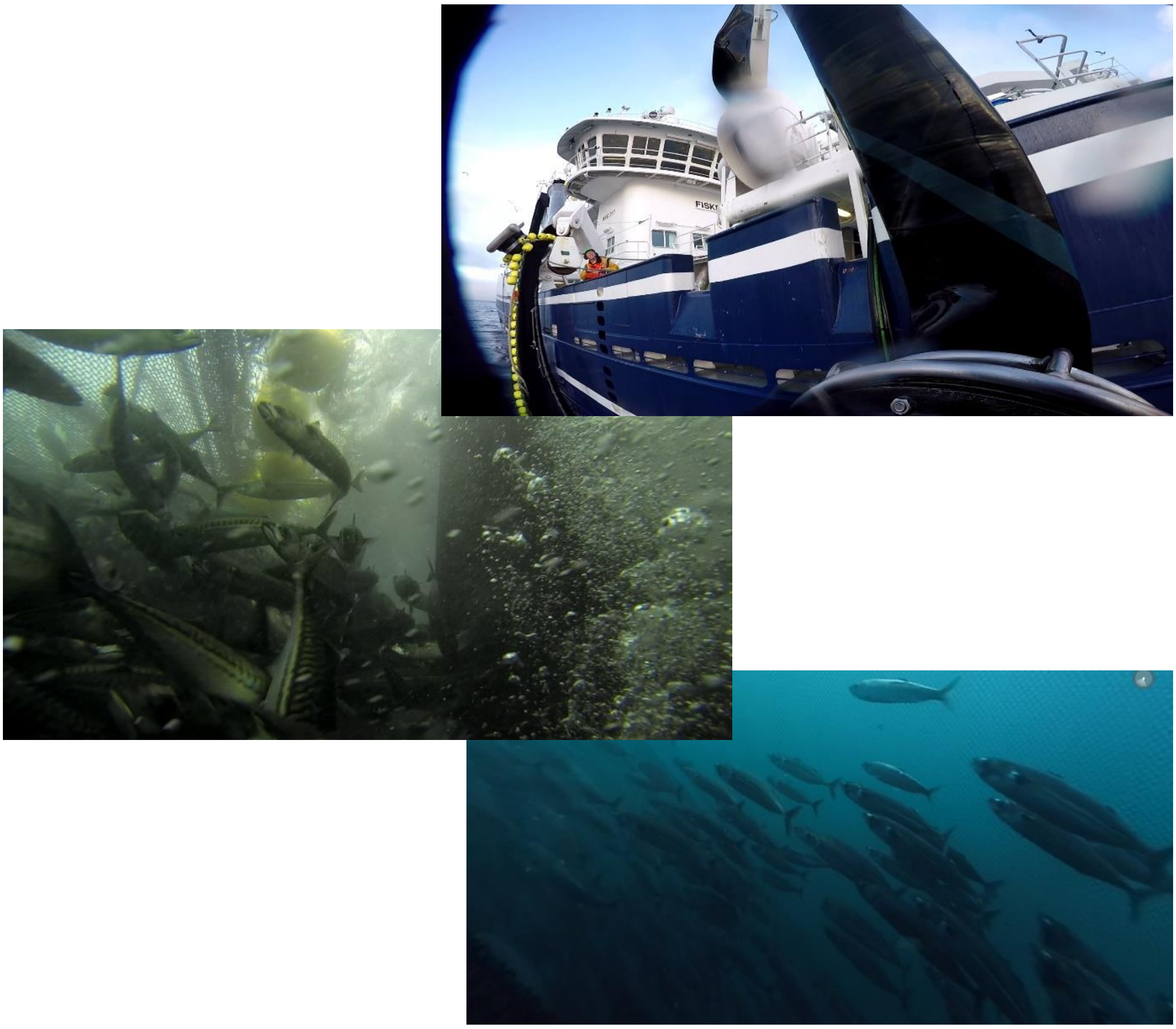


1. Background and cruise objectives

This cruise supported the project "Catch control in seine fishing for pelagic species" funded by fisheries and the aquaculture industry's research fund. The main objective of the project is to improve catch control in purse seine fishing by developing instruments and analysis methods that provide a better basis for decisions during the catching process. During the cruise, the goal was to test various optical and acoustic methods that can provide information about the species and size composition of the catch. In addition, shoal and individual behaviour was monitored with sonar and camera from before the cast until the fish was taken on board or released as a basis for a better understanding of the fish's reaction to catch. They also wanted to investigate how catching and handling stress affects the quality of the fish raw material and survival during release, and in this connection measure the fish's vitality during pumping and in the tank and register environmental conditions during the entire catching process.

The main objectives of the cruise were to:
- Develop and test optical and acoustic instruments and methods for monitoring fishing behaviour and catch composition during fishing with nets.
- Study how catch handling affects the fish's welfare and thereby survival after release from net and quality.

1.1. Planned Activities

1. Testing of Stereo Camera Systems to estimate mean fish size in schools before and during early capture (Section 3).
2. Echosounder measurements of mackerel for individual size and school characteristics with flying drone (Section 4).
3. Monitoring of catch and handling stressors and fish behaviour during capture (Section 5).
4. Effect of capture and handling stress on catch vitality and welfare (Section 6).

2. Cruise Narrative

In summary, during the fifteen day research cruise (21st September to 4th October, 2020) there were a total of 9 casts (see table 1 for details): one practice cast (#01); three missed catches (#04, #07 and #08); and five successfully taking catches ranging from 62 to 310 tonnes (#02, #03, #05, #06 and #09). Four days were used to deliver catch, including transiting to/from the fishing grounds, although during these periods the scientific crew used time to calibrate and maintain instruments, as well as process data. Two days were lost due to bad weather (24 & 24/09/20), when FV Fiskebas sheltered in Lerwick.

The research cruise began on 21st September, 2020, at Nykirkekaien, Bergen, where the vessel (FV Fiskebas) was loaded and prepared. To reduce the risk of infections from COVID-19 during the cruise, the fishing and scientific crews had observed a ten-day quarantine (in accordance with national and institute guidelines), as well as following good hygiene practices and socially distancing guidelines while aboard, where practical. In addition, all scientific crew members presented signed self-declaration forms to the skipper before embarkation, stating that they had not knowingly been exposed to COVID-19 infection and were free of symptoms. In attempt to further reduction risk of COVID-19 infection, the crew (fishing and scientific) were not permitted ashore when in non-Norwegian ports.

FV Fiskebas left Bergen harbour at 18:08 (UTC; 20:08 local time) on 21st September, 2020 and conducted trials in Byfjørden to test the stereo-cameras systems (probe and ROV) in collaboration with Mohn Tech AS (see section 3). We then proceeded directly towards fishing grounds in the UK sector, south east of Shetland, where there had been recent reports of mackerel school activity. En route, a test cast with the purse seine [59.6173 N, 3.0057 E] was conducted to practice the controlled slipping procedure, as well as deploying instruments and data recording routines.

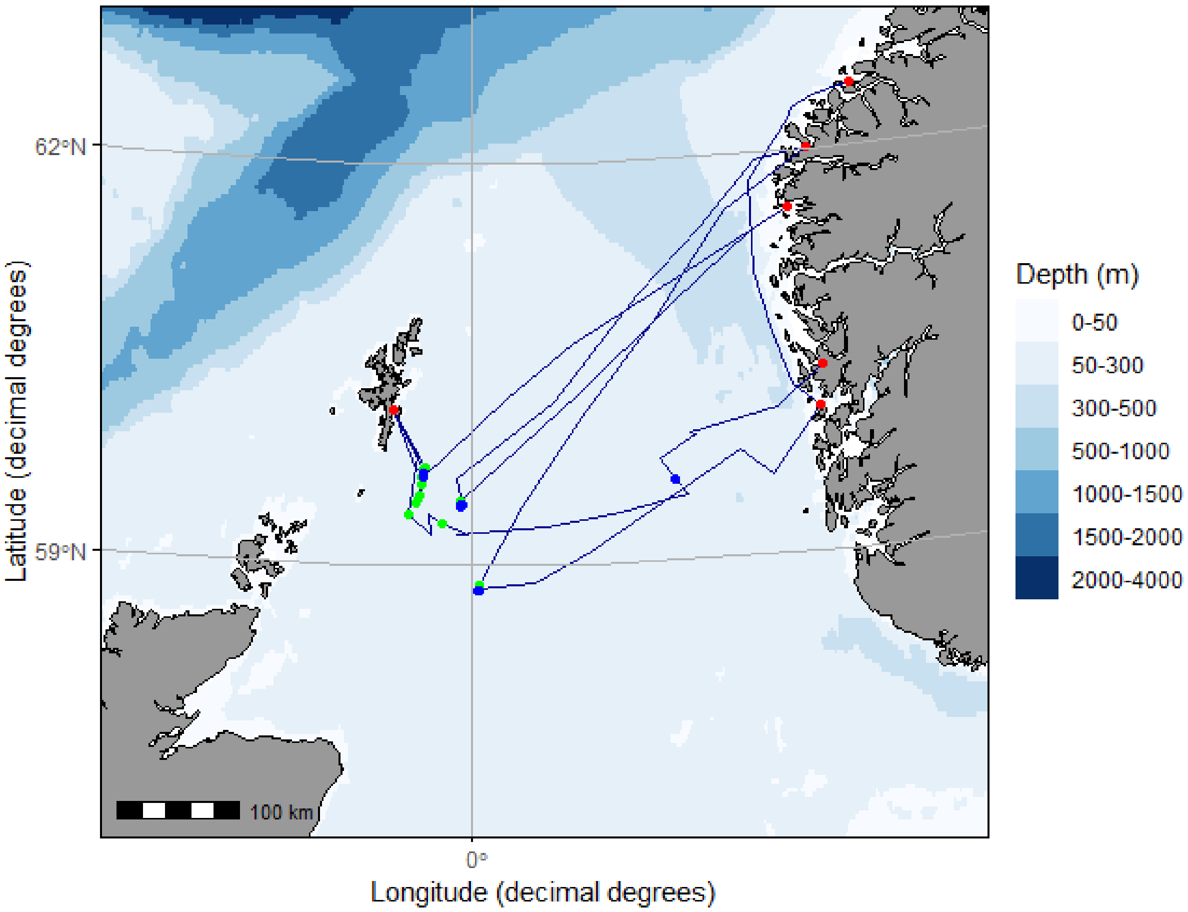


Figure 1: Chart of the cruise track (blue line), stereo trial positions (green points) and purse seine cast positions (blue points). Harbours are shown as red points, including Lerwick (Shetland) and the Norwegian harbours: Ålesund, Selje, Florø, Bergen and Storebø (from North to South).

The vessel arrived at the target fishing grounds, approximately 50 nm SE of Sumburgh Head, at ~0530 UTC. We then proceeded to search for potential target mackerel schools, which would be surveyed with the stereo-camera systems, while the crew took handline samples to obtain size measurements and stomach samples (see section 3.3). From the stomach sampling, it was determined that there was a relatively high proportion of fish (30-40%) containing red dinoflagellate (RD) phytoplankton. This meant the skipper did not want to take any catches in this area, because such high RD content can spoil the catch quality. It was agreed that we would continue searching in area for the rest of the day, conducting measurement surveys with the stereo-cameras systems, as well as taking handline samples. That evening, FV Fiskebas sailed to Lerwick to shelter from a forecast storm. While in Lerwick, all crew remained on board, and the scientific crew-maintained equipment and began processing data.

We left Lerwick at 04:00 UTC on 25th September and began searching for mackerel on the same fishing grounds as previous. A further nine stereo-surveys were conducted, with corresponding fish samples caught by handline, until we were forced to return Lerwick to again shelter from bad weather. The fish samples revealed that the RAD content had dropped to 10-15%, indicating that it may be possible to fish after the storm had passed.

The search for mackerel recommenced on the morning of 27th September, when a further three stereo-surveys were conducted. The associated fish samples confirmed that the RDA was at acceptable levels and the first purse seine cast was taken at 11:30 UTC. During this and subsequent casts, the behaviour, vitality and physiology of the catch was monitored during the catch and while being pumped aboard to determine the stress/welfare status during the capture process (see sections 5 and 6). Two casts were taken and monitored that day, catching a total of 395 tonnes of mackerel (table 1), which was delivered to Florø on 28th September. FV Fiskebas returned to the fishing grounds on 29th September, where one stereo-survey was conducted, followed by four purse seine casts, two of which successfully caught a total of 144 tonnes (table 1). This catch was landed at Selje on 01st October, where there was also a change of scientific crew, including taking aboard a team from BirdView AS.

In the next phase of the cruise, the emphasis during pre-catch surveys would be shifted from the stereo-camera systems to testing a flying-drone deployed echo-sounder system in collaboration with BirdView AS (see section 4). FV Fiskebas left Selje at 16:45 UTC on 1st October and sailed back to the fishing grounds south-east of Shetland, where a large fishing fleet had now assembled. Arriving on the grounds late at ~1030 UTC on 2nd October, two stereo-surveys were conducted, before commencing fishing operations in the afternoon. Unfortunately, due to technical difficulties and seasickness in the BirdView team, it was not possible to conduct any trials with the drone. However, two purse seine cast were conducted and monitored, with the second taking a catch of 63 tonnes (including 4 tonnes of herring, as bycatch) (table 1). This was delivered to Storebø on the morning of 3rd October. While at

Storebø, we took advantage of the calmer conditions to test the drone and calibrate its Simrad EK80 echosounder.

On the afternoon of 2nd October [~1445 UTC], the vessel began passage to Møre, near Ålesund, where mackerel catches had been reported in relatively calm waters inshore. We arrived early on 3rd October and began searching for mackerel schools at ~0600 UTC. During the search, it became clear that there would be limited opportunities to take a catch in this area, because the mackerel schools appeared agitated and avoiding approaching vessels and were sheltering in shallow water. It was decided to prioritise the drone operations but, unfortunately, due to further technical difficulties, we were unable to deploy the drone on a mackerel school. The scientific crew (including the BirdView team) disembarked FV Fiskebas at 1400 UTC in Ålesund. All scientific equipment remained on board in preparation for the next research cruise [2020851].

Note – included in the objectives of the next research cruise [2020851] was to repeat the monitoring of behaviour and vitality of the catch (sections 5 and 6) in a herring fishery (Tenningen et al, 2020). Due to bad weather and area closures in the herring fishing grounds, it was decided to collect more data in the mackerel fishery, which was still ongoing. This resulted in an additional four casts being taken on 16th October, with three catching a total of 485 tonnes of mackerel (table 1). For clarity and completeness, the results from these are also reported here as casts B01 – B04 (sections 5 and 6).

Table 1: Overview of purse seine casts and mackerel catches during cruises 2020823 and 2020851 (FV Fiskebas).

Cast	**Date**	**Position (decimal)**		**Fisking time (UTC)**		**Wind**		**Current (50 m)**		**Waves**	**Catch**		**Instrumentation / observations**							**Notes**
		Lat.	Lon.	Start	Stop	Speed (m/s)	Dir. (°)	Speed (kn)	Dir. (°)	(m)	Catch weight (t)	Mean Indiv. Wgt (g)	Stereo Cam	CMP (net)	CMP (pump)	CMP (RSW)	Geil Cam (V&H)	Drop Cam	VA	
Tokt 2020823																				
1	22-09-20	59.6173	3.0057	8:09:00	9:45:55	11	180	0.5	323	0.75	NA	NA	A, B	N	N	N	(Y)	N	N	Test slipping
2	27-09-20	59.6893	-0.6960	11:33:58	13:18:44	14.1	45	0.3	230	2	85.1	457	A, B	Y	Y	Y	N	N	P,R	incl. Stereo #14
3	27-09-20	59.6623	-0.7160	14:30:54	16:25:54	6	45	0.4	321	1.25	309.6	468	N	Y	Y	Y	N	N	P,R	
4	29-09-20	59.4518	-0.1458	11:46:53	12:50:01	6	230	0.6	318	<0.5	0	NA	N	N	N	N	N	N	N	no catch
5	29-09-20	59.4510	-0.1530	13:23:52	14:55:02	4.5	230	1.1	340	<0.5	62.4	440	N	Y	Y	Y	N	N	P	large school
6	29-09-20	59.4375	-0.1537	15:26:52	17:10:38	3.4	225	0.6	4	<0.5	81.6	454	N	Y	Y	N	N	N	P	
7	29-09-20	59.4578	-0.1333	17:31:01	18:42:38	5.6	200	0.8	20	<0.5	0	NA	N	N	N	N	N	N	N	no catch
8	02-10-20	58.8247	0.1028	15:32:42	16:32:55	5	90	0.4	203	2	0	NA	N	N	N	N	N	N	N	no catch
9	02-10-20	58.8195	0.1087	17:24:00	18:53:49	3.5	90	0.4	32.5	1.25	63.2	473	N	Y	Y &	Y	N	N	P,R	incl. 4t herring bycatch
Tokt 2020851																				
B1	16-10-20	58.8080	-0.8849	6:57:58	8:27:20	5	22.5	0.4	60	1 - 1.5	44.2	472	N	Y	Y	Y	N	N	P,R	Mackerel
B2	16-10-20	58.7790	-0.8894	8:56:15	10:24:46	7	22.5	0.4	60	1 - 1.5	33.6	439	N	Y	Y	Y	N	N	P,R	Mackerel
B3	16-10-20	58.7098	-0.8471	10:49:25	11:53:19	8	22.5	1.3	164	1.5	0	NA	N	Y	N	N	N	N	N	Slipped
B4	16-10-20	58.6635	-0.8283	12:41:27	15:00:51	6.7	45	0.8	136	1.5	406.5	444	N	Y	Y	N	N	N	P	Mackerel

Y = deployed; N = not deployed; F = deployed but failed

A = stereo probe; B = stereo ROV; § = too darkt; & = no oxygen measurement

P = Vitality Assessment (VA) during pumping; R = VA in RSW tank

3. Testing of Stereo Camera Systems to estimate mean fish size in schools before and during early capture.

This section describes trials testing the operation of the stereo-catch monitoring probe (S-CMP)(section 3.1) and Mohn Technology's stereo-ROV system ("Fishbot 2") (section 3.2), as well as results of trials to measure mackerel in either target or captive schools using these systems, during commercial fishing operations (section 3.3). For more details of the stereo-camera development and testing during this project, including the Intel RealSense stereo camera system and Mohn Technology software used to analyse stereo images, see Breen et al (2021).

3.1. Operation of Stereo Catch Monitoring Probe (S-CMP) during commercial fishing operations.

The objective of this trial was to test the functionality of the stereo-catch monitoring probe (S-CMP) for deploying a stereo-camera system to measure mackerel in either target or captive schools, during commercial fishing operations. The platform was a development from the Catch Monitoring Probe (CMP) for monitoring fish behaviour and environmental parameters in the catch during the capture process (Breen et al, n.d.)(see section 5). Following operational trials, the S-CMP would then be used to measure fish before and during capture, to test the stereo-camera system's ability to estimate the mean size of individual fish within a target school (see section 3.3 for details and results).

Figure 2: Stereo Catch Monitoring Probe (S-CMP) ready for deployment during the research cruise on M/F Fiskebas. The floatation section and the camera section are connected, with the support line and cable pass through the float so that the depth of the camera relative to the surface can be controlled. This version is fitted with an Ethernet cable, for direct camera feed from the probe, as well as additional weight and floatation to stabilise the camera's vertical position in the water.

Narrative: Sea-trials began on 21st September 2020 in Byfjorden, with a wet-test deployment of the S-CMP to ensure the WiFi communications were functioning correctly. A further wet-test was conducted on 22nd September, during a test-cast of the purse seine. In Byfjorden, sea-conditions were calm and the WiFi communications worked well, with signals only being lost when the S-CMP drifted out of line-of-sight from the receiving antenna on the vessel. However, during the stereo-trials in the fishery (see below), where there was increased wave-action, WiFi communications were more intermittent, with the live feed camera images frequently freezing, as well as losing control of the camera system when it was deployed in the water.

The periodic submerging of the antenna caused by wave-action can lead to fluctuations in Voltage Standing Wave Ratio (VSWR; a measure of radio-frequency power transmission) which will interrupt transmission of the signal to the vessel and can potentially damage the system. In an attempt to avoid this happening, more floatation was added to keep the aerial at a height of approx. 125mm (i.e. greater one wavelength in 2.4GHz radio transmission band) above the sea-surface, but this was only partially successful. In addition, the power output was increased, in an attempt to overcome the communication problems and allow the S-CMP to be deployed to a greater depth. That is, to increase depth required a longer coax cable between the WiFi transmitter and antenna, which led to increased attenuation of the RF signal. Therefore, to maintain RF transmission strength, it was necessary to increase the output power from 0.1 watts to 0.2 watts. After several days the WiFi communications failed completely. It was discovered that the WiFi component had burnt out. This was suspected to be caused by the antenna periodically submerging generating very high fluctuations in VSWR, in combination with the high-power output.

There was a total of 17 pre-cast stereo-observation trials (ST01-17) and three casts in which stereo-observations were attempted (Table 2). Of these, the S-CMP was deployed 12 times: 6 with successful stereo recordings (see section 3.3 for further details and stereo measurement results); 3 when the camera failed to operate; and 3 where it was not possible to view the mackerel. The first two camera failures were suspected to be due to the poor WiFi communications shutting down the camera and/or onboard computer. However, a further failure on the 29-09-20 (after the WiFi comms had been removed) confirmed that the premature shut-downs were most likely due to the acceleration / deceleration forces during deployment. Although, this had not been an issue with other instrumentation used in the original CMP (Breen et al, n.d.).

Although the stereo-camera system did not rely on a live feed to the vessel, because all images were recorded in the onboard computer, lack of live images did hamper stereo-observations. Without live images, it was not possible to confirm the S-CMP was close enough to the school to make successful stereo-image recordings. Therefore, on 30th September it was decided to convert the S-CMP to have communication directly to the vessel via an Ethernet cable. This would guarantee a live camera image to the vessel, if the camera was operational, and would allow direct control of the camera and onboard computer during observations. However, the S-CMP would no longer be able to be deployed using the canon. Instead, the probe was lowered from the vessel-side. This eliminated the hardware failures, while still being able to collect stereo data. A wet-test of the system was successfully conducted on 01-10-20, and two successful deployments were made on 02-10-20.

To allow analysis of the stereo-images recorded by the S-CMP it was necessary to download image from the camera via the communications link (WiFi or Ethernet cable). This was a slow process, typically taking 1.5 x recording time with the WiFi and 0.3 x recording time with the Ethernet. This inevitably delayed the turn-around time for the next deployment of the S-CMP, but also limits any plans to develop this into a “real-time” analysis system. However, this process could be made substantially quicker by using a USB memory stick to store images instead of storing them locally on the UP board. This is not supported currently, because a special script is required to mount USB stick on the UP board system, but its implementation would give a recording time of more than 60 minutes (limited by onboard memory size of UP board) and a quick turnaround time on the probe (just change USB stick and battery) before new deployment.

In conclusion, this trial demonstrated that the S-CMP can be successfully used to enable the stereo-camera system to measure mackerel in either target or captive schools, during commercial fishing operations. The importance of maintaining reliable communications with the stereo-camera systems to view live images, as well as control the camera system, was emphasised during these trials. Moreover, if this system is to be developed to enable “real-time” analysis of the target school’s mean size characteristics, reliable and fast communications will be imperative.

Table 2: Summary of Stereo-cam deployments using the Stereo-Catch Monitoring Probe and the ROV ("FishBot 2").

Trial	**Date**	**Time (UTC)**		**Position (Decimal)**		**Fish Aggregation**	**Stereo Instruments Deployed**	
#		Start	End	Lat	Long	Notes	Probe	ROV
ST_01	23-09-20	7:22	7:55	59.313	-0.420	Thin - 10-20m deep	N	Y - no fish images
ST_02	23-09-20	14:43	15:56	59.389	-0.912	Large school; 5-50m deep	Y (15m) - Good images	Y – OK images
ST_03	25-09-20	9:00	9:23	59.531	-0.742	Too thin for ROV	N - school too deep	Y - no fish images
ST_04	25-09-20	9:54	10:10	59.501	-0.783	Thin layer; 15-40 variable	N - school too deep	Y – poor images
ST_05	25-09-20	10:56	11:00	59.491	-0.790	Large ~1000t; > 15m deep	[Y (15m) - stopped early, no images]	N - problem with thruster
ST_06	25-09-20	11:24	11:43	59.468	-0.814	Large; 15-20m	N - in prep for depth test	Y – Good images
ST_07	25-09-20	13:37	13:56	59.605	-0.737	Herring only	Y (36m) - no mackerel	Y - no mackerel
ST_08	25-09-20	14:42	14:59	59.724	-0.705	Thin; ~30m	N	N
ST_09	25-09-20	15:03	15:13	59.726	-0.686	Too deep; ~40m	N	N
ST_10	25-09-20	15:21	15:36	59.738	-0.676	School; 20-50m	Y (36m) - OK images	Y – OK images
ST_11	25-09-20	16:11	16:35	59.728	-0.685	10-20 low density; 20-35 mid density	Y (36m - with RINKO) - no fish images	N - problem with thruster
ST_12	27-09-20	10:08	10:25	59.720	-0.712	10-20m - disturbed by approach => 20-35m => 10-25m thin	Y (36m) - few fish images, fish dispersed as deployed	N
ST_13	27-09-20	10:39	10:52	59.705	-0.697	22-35m thin	[Y (36m) - failed to start up]	Y - no fish images
ST_14	27-09-20	11:02	11:15	59.693	-0.700	30-40m => 33m thin	Y (36m) - OK images	N
Cast_02	27-09-20	11:34	12:57	59.689	-0.707	In net	N	Y - in Net, Good images
Cast_03	27-09-20	14:30	15:34	59.663	-0.719	In net	N	Y - thrusters fail - poor images
ST_15	29-09-20	11:05	11:15	59.478	-0.159	15-35m; densest at 30m	Y (36m => hauled shallower) - OK images	N
Cast_05	29-09-20	13:09	14:31	59.451	-0.153	In net	[Y] In Net, but shut down on deployment	N
ST_16	02-10-20	12:50	12:55	58.855	0.117	18-30m	Y (Cable @ 25m; RINKO) - no images; start recording as passed out of school	N
ST_17	02-10-20	13:04	13:53	58.824	0.112	25-40m => 20-40m	Y (Cable @ 25m; RINKO) -poor images i) sunglare; and ii) fish distant & below	N

Notes :–

1) successful deployments, where usable stereo images were recorded are highlighted in green.

2) failed deployments, due to technical problems, are highlighted in yellow.

3.2. Operation of ROV ("FishBot 2") during commercial fishing operations.

The objective of this trial was to test the functionality of an improved ROV platform ("FishBot 2") for deploying a stereo-camera system to measure mackerel in either target or captive schools, during commercial fishing operations. The improved ROV platform had been fitted with larger batteries, higher capacity thruster controllers and heavy-duty cables supplying the thrusters, to improve operational performance. In addition, instrumentation had been added to improve piloting of the vehicle when the pilot did not have a direct view of the ROV, including: gyro-compass and depth meter, as well as tilt, roll and yaw sensors. Following operational trials, the ROV would then be used to measure fish before and during capture, to test the stereo-camera system's ability to estimate the mean size of individual fish within a target school (see section 3.3 for details and results).

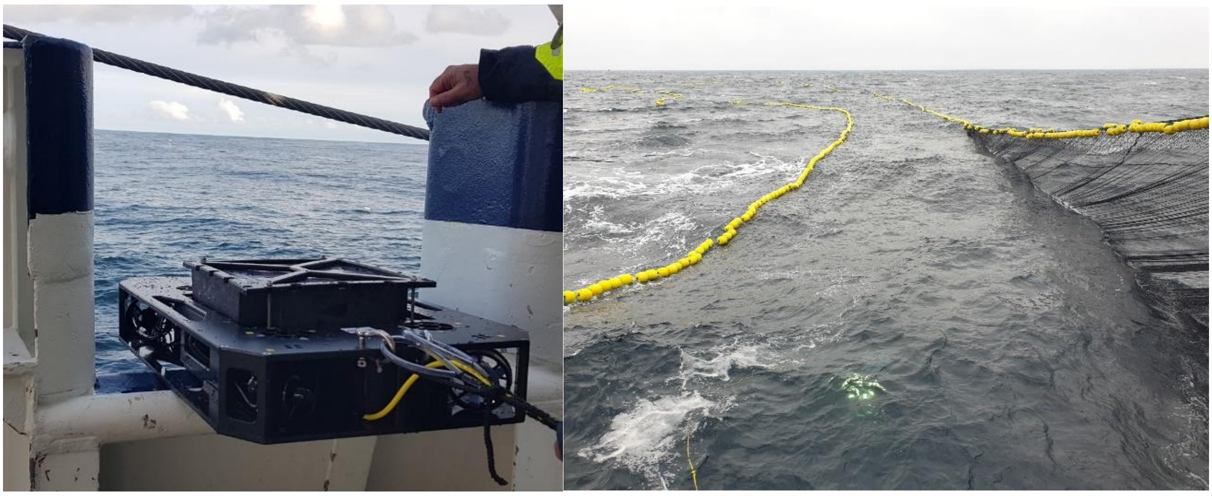


Figure 3 – Left: the ROV ("FishBot" Mk II), in preparation for deployment; and Right: the ROV (with lights on) inside the purse seine during commercial fishing operations (hauling).

Narrative: Before starting the stereo observation trials (see below), there were two successful wet-test deployments of the ROV alongside the S-CMP stereo platform. The ROV was deployed from the starboard side of the vessel, forward of the triplex winch. This method worked well and did not interfere with the fishing operations.

During the stereo observation trials, FishBot was deployed 10 times, both inside and outside the purse seine (table 2). There were eight "pre-cast" trials (i.e. with no purse seine net) were the ROV was successfully deployed. Of these, there were four where FishBot was able to locate the mackerel school and make successful stereo recordings for later analysis. A further two successful stereo recordings were made in casts 02 and 03 (See section 3.3 for further details and stereo measurement results).

On two occasions, the ROV could not be deployed because of problems with the thruster controllers. After the first thruster failed, it was necessary to drive with six or seven operational thrusters instead of all eight. This caused some instability and less thrust while navigating the ROV, but it was still possible to operate. When a third thruster malfunctioned during Cast 03, the ROV operations were abandoned for the rest of the cruise. However, FishBot did manage to record some stereo images from Cast 03 for later analysis.

The lights on FishBot were not used while recording fish video due to back-scattered reflections from particles in the water. Further investigation into placement, brightness and light type will be performed if that proves necessary.

In conclusion, the setup and operation of the ROV generally worked well and Mohn Technology were able to perform trials before and after setting of the purse seine. Mohn Technology are optimistic about the opportunities for this product and think it can be a valuable tool for fishermen, if it is developed to be user friendly and reliable during operation.

3.3. Measurements of Wild Mackerel in a Commercial Fishery

This section will describe the results of the stereo camera estimates of fish length from those deployments, in comparison to estimates from samples taken from the observed mackerel schools.

Methods: On arriving at the fishery, it was noted that the mackerel were feeding on red dinoflagellate (RD) phytoplankton. Therefore, no attempt to take catches was made until it was demonstrated that the RD had left the area and the mackerel stomachs were clear. During this period, the sampling strategy was to take observations and samples from target schools, without setting the purse seine to catch them. This would mimic a "pre-catch survey" to characterise the species and size composition of a target school. Details of these surveys (ST_01 to ST_17) are given in table 2.

On sighting a target school on the vessel's sonar, the stereo deployment platforms were made ready. The vessel would then approach the school, attempting to position itself over the target school without initiating an adverse response in the fish – i.e. when the fish would swim down and away from the vessel, beyond the range of the stereo platforms. The S-CMP and the ROV were deployed over the starboard side of the vessel, while the skipper tried to ensure the vessel drifted to port, thus avoiding taking the platforms' cables under the vessel. At the same time the S-CMP and ROV were deployed, the vessel's crew began taking a sample from the school using handlines on the port side of the vessel. The aim was to catch at least 50 fish, which would be individually measured and weighed.

Of the seventeen attempted "pre-catch surveys", eight successfully obtained both stereo images and viable fish samples (table 2). Of these, the S-CMP was deployed 12 times: 6 with successful stereo recordings; 3 when the camera failed to operate; and 3 where it was not possible to view the mackerel (see section 3.1 for more details). The ROV was deployed eight times during the "pre-catch surveys", of which there were four where FishBot was able to locate the mackerel school and make successful stereo recordings for later analysis (see section 3.2 for more details).

When the RD swarm had moved and there was an opportunity to take catches, the "pre-catch survey" strategy was continued. The ROV made a further two successful stereo recordings in casts 02 and 03, with the S-CMP providing pre-catch survey data for cast 02 from survey ST_14. At this point, the S-CMP had been converted to a hardwire system and, as a result, could no longer be deployed inside the net (see section 3.1). Moreover, during cast_03 the ROV's thruster controller failed and the ROV was retired for the remainder of the cruise (section 1.2). The stereo images were analysed using Mohn Technology Measure (Breen et al, 2021).

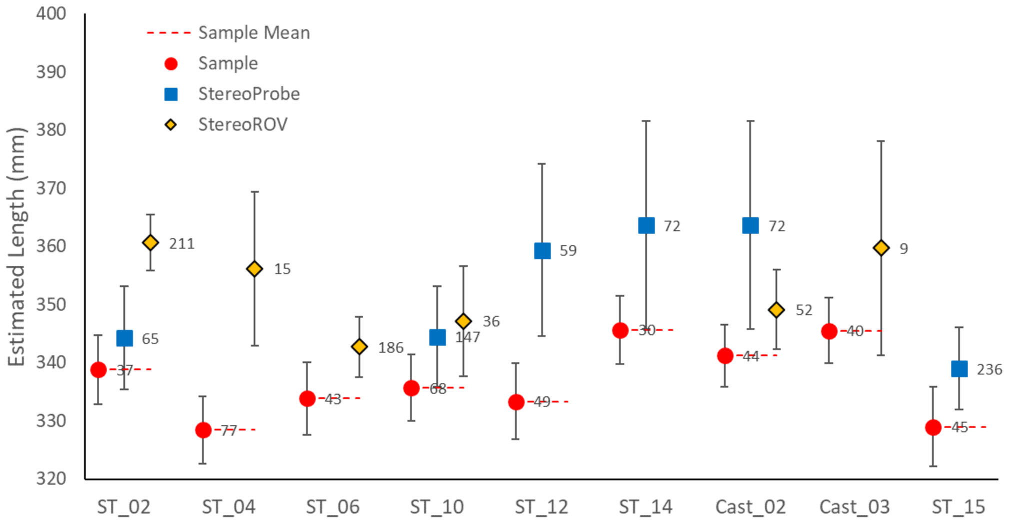


Figure 4: Overview of the mean length estimates (with 95% confidence intervals) for fish samples (red dots), Stereo Catch Monitoring Probe (S-CMP; blue squares) and Stereo ROV ("FishBot 2"; yellow diamonds). Sample sizes (n) are shown to the right of the data points.

Results

The mean size of mackerel from the physical samples was 336.8 mm (mean of means) with a mean 95% confidence interval (CI) across the samples of 6.0 mm, and a mean of 48.1 fish per sample. There was relatively little variation between sample means, with a minimum of 328.4 mm and a maximum of 345.7 mm. Figure 4 gives an overview of each of the stereo survey estimated lengths for these samples, measured using the S-CMP and ROV platforms. In general, the stereo estimates typically measured more fish per sample (mean = 108.5 for S-CMP; and 84.8 for ROV) and always overestimated the mean length of their respective physical sample. Furthermore, estimates varied more for both platforms (S-CMP and ROV): 339.0 to 363.6 and 342.8 to 360.6, respectively. Despite this, measurement error in all samples was less than the global target of 10%, moreover the majority of samples (7 out of 12) were less than the preferred target of 5% (figure 5).

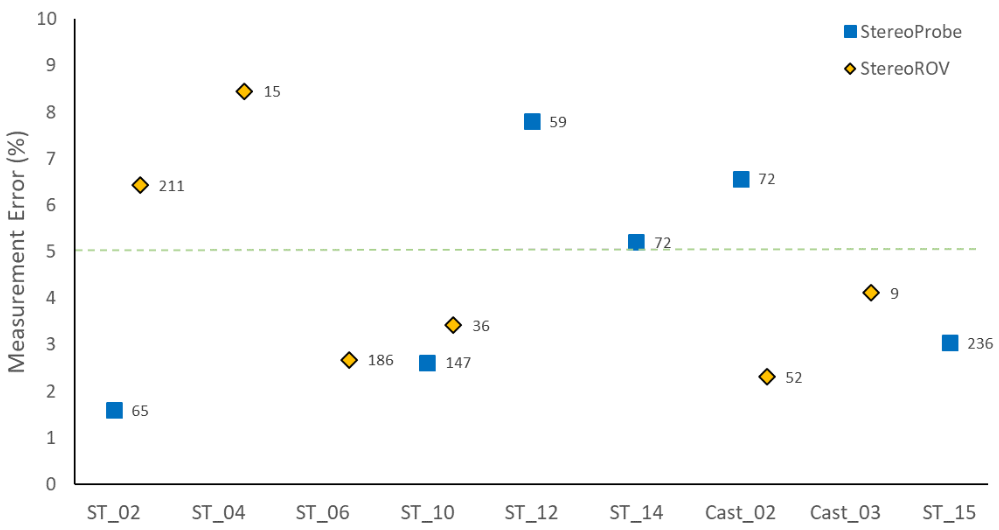


Figure 5: Overview of the length measurement errors for the Stereo Catch Monitoring Probe (S-CMP; blue squares) and Stereo ROV ("FishBot 2"; yellow diamonds). Sample sizes (n) are shown to the right of the data points. A green horizontal line shows the ideal target for accuracy (i.e. 5% error).

To assess for potential distance related bias in the measurements, the relationship between distance to camera and individual fish length estimates was modelled using simple linear regression (table 3). This analysis showed that 8 out of 12 surveys had significant positive relationships ($p < 0.05$) between distance and individual length estimates; 5 for the S-CMP and 3 for the ROV. Following the recommendation from the Austevoll trials, i.e. to restrict measurements to fish within <3m of the camera (Breen et al, 2021), additional analysis was conducted on a reduced dataset of fish measured only at distances of <3m, to assess whether this would reduce the effects of this distance related bias. These results are also shown in table 3, with relevant lines printed in italics. For the S-CMP data, this analysis could only be conducted for three of the available survey sets, because the other three sets had no fish which were less than 3m from the camera. Of the three S-CMP that could be reanalysed, two did marginally reduce the error (ST02_Probe and ST10_Probe), but the latter of these substantially increased its CI, from 8.6 to 13.3, and did not eliminate the distance related effect. The third set (ST15_Probe) increased both its measurement error (3.04 to 4.98) and CI (7.1 to 46.9), primarily because of a drastically reduced sample size (from 236 to 8). For the ROV, this analysis could be conducted on four of its six sets; Casts 02 and 03 had no fish that were further than 3m from the camera, so any comparative analysis was pointless. Of these, three (ST02_ROV, ST06_ROV and ST10_ROV) had their errors reduced but all increased CI, and none had the distance related effect removed in the remaining data. The fourth set (ST04_ROV), increased both error and CI, and like ST15_Probe, there was no distance related effect to begin with. In summary, restricting a dataset to fish measured <3m from the camera can reduce measurement error in samples were there is a significant distance related effect, but it is likely to reduce precision (increase CI) unless sufficiently large sample sizes can be maintained. Moreover, it did not remove any residual distance related effect in the datasets. However, in datasets where there was no significant distance related effect, both measurement error and CI increased. In conclusion, attempting to remove the inherent distance related bias in the stereo-camera system used in this study by limiting the data to fish measured within 3m of the camera does not appear to be an optimal solution.

Table 3: Linear Regression Model Results for the relationship between estimated fish length and distance from camera from the stereo camera surveys from the Stereo Catch Monitoring Probe and the ROV (shaded in blue). Also shown are the corresponding sample size (n), measurement error (in %) and confidence interval for estimated length (CI). Lines in italics are models based on a reduced data set of fish measured at distances <3m.

Model	**Coefficients**				**ANOVA**				**Measurement**		
	Intercept	se	Distance	se	residual df	R^2	F	p	n	Error	CI
ST_02_Probe	308.8	14.3	0.014	0.006	63	0.097	6.804	0.0113	65	1.60	8.9
ST_02_<3_Probe	*317.3*	*22.0*	*0.009*	*0.011*	*44*	*0.018*	*0.789*	*0.3794*	*46*	*-0.71*	*8.8*
ST_02_ROV	284.6	17.5	0.024	0.006	209	0.084	19.195	0.0000	211	6.43	4.8
ST_02_<3_ROV	*230.3*	*58.3*	*0.044*	*0.021*	*80*	*0.052*	*4.430*	*0.0385*	*82*	*4.08*	*7.6*
ST_04_ROV	362.0	37.5	-0.002	0.013	13	0.002	0.025	0.8780	15	8.45	13.2
ST_04_<3_ROV	*292.7*	*59.7*	*0.027*	*0.023*	*8*	*0.152*	*1.435*	*0.2652*	*10*	*10.75*	*17.0*
ST_06_ROV	298.1	9.7	0.019	0.004	184	0.111	22.976	0.0000	186	2.68	5.2
ST_06_<3_ROV	*273.5*	*13.6*	*0.031*	*0.006*	*145*	*0.146*	*24.701*	*0.0000*	*147*	*1.75*	*5.7*
ST_10_Probe	276.4	19.3	0.020	0.006	145	0.083	13.042	0.0004	147	2.63	8.6
ST_10_<3_Probe	*154.8*	*73.0*	*0.065*	*0.027*	*50*	*0.102*	*5.685*	*0.0210*	*52*	*-2.23*	*13.3*
ST_10_ROV	295.9	18.4	0.021	0.007	34	0.193	8.147	0.0073	36	3.42	9.5
ST_10_<3_ROV	*241.4*	*19.4*	*0.046*	*0.008*	*27*	*0.520*	*29.294*	*0.0000*	*29*	*2.71*	*9.9*
ST_12_Probe	286.0	56.5	0.014	0.011	57	0.029	1.717	0.1953	59	7.80	14.9
ST_14_Probe	139.9	53.2	0.042	0.010	70	0.206	18.119	0.0001	72	5.21	17.9
ST_14_Probe	139.9	53.2	0.042	0.010	70	0.206	18.119	0.0001	72	6.57	17.9
Cast_02_ROV	346.9	19.5	0.001	0.010	50	0.000	0.014	0.9074	52	2.31	6.8
Cast_03_ROV	333.9	31.2	0.010	0.012	7	0.095	0.735	0.4196	9	4.11	18.4
ST_15_Probe	365.4	19.9	-0.006	0.004	234	0.008	1.815	0.1792	236	3.04	7.1
ST_15_<3_Probe	*412.4*	*256.9*	*-0.026*	*0.097*	*6*	*0.011*	*0.069*	*0.8022*	*8*	*4.98*	*46.9*

There were clear differences in the distances from which the two platforms measured their respective targets (figure 6). The ROV was able to achieve a mean distance between camera and fish of less than 3m in all but one of the samples (figure 6), and that rogue sample was very close with a mean distance of 3146 mm. Conversely, the S-CMP only once achieved a mean distance between camera and fish of <3 m. It was anticipated that this would adversely affect the measurement error in the S-CMP data, because of the inherent distance related bias in the stereo-camera system. Although there was an apparent increase in measurement error with increasing mean distance from the camera (figure 7), this appears to have affected the ROV measurements more profoundly, despite most ROV measurements being within the 3m target range. As a result, the range of measurement errors in both systems was comparable (figure 7).

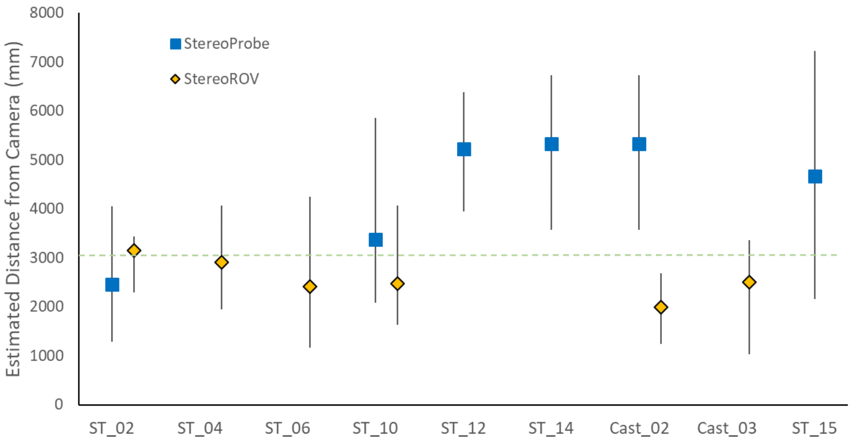


Figure 6: Overview of the mean estimated distance from the camera (with maximum and minimum range) for the Stereo Catch Monitoring Probe (S-CMP; blue squares) and Stereo ROV ("FishBot 2"; yellow diamonds). A green horizontal line shows the ideal target approach distance (i.e. <3 m).

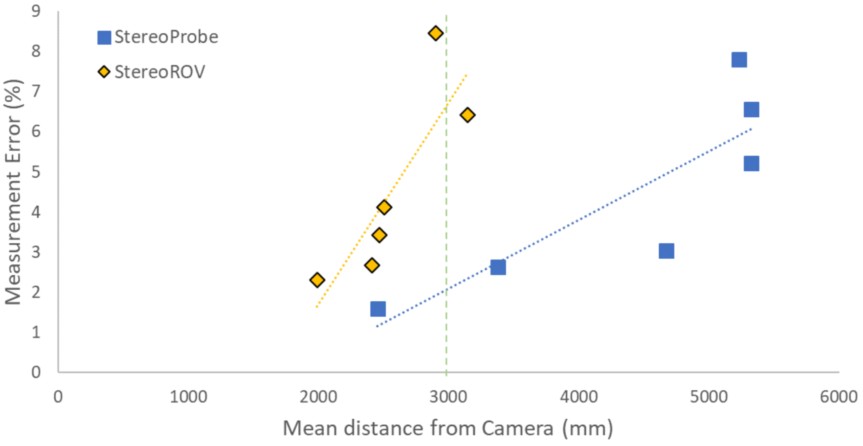


Figure 7: Overview of the length measurement errors (as a measure of accuracy) from the Stereo Catch Monitoring Probe (S-CMP; blue squares) and Stereo ROV ("FishBot 2"; yellow diamonds) with respect to distance from the camera. A green vertical line shows the ideal target approach distance (i.e. <3 m).

In conclusion, these sea trials have demonstrated that both the Stereo ROV ("FishBot 2") and Catch Monitoring Probe (S-CMP), and supporting MT Measure software, were capable of estimating the mean length of target schools with less than a 10% error for all estimates, and less the a 5% error for the majority. However, it was also demonstrated that there is an inherent distance related bias, which is impacting the accuracy and precision of these estimates. Attempts to address this bias by limiting the dataset to fish only measured within three metres of the camera had only marginal effects on improving accuracy of estimates and generally reduced precision. The deployment platforms performed well, with some technical challenges (see sections 3.1 and 3.2). The ROV was consistently able to get measurements closer to the mackerel than the S-CMP. Despite this and the distance related bias, there was no apparent difference between the two platforms with respect to overall accuracy and precision of estimates. The reason for this is unknown, but future work should investigate the potential for differences in image stability and fish evasion behaviour on measurement accuracy and precision.

4. Echosounder measurements of mackerel for individual size and school characteristics with flying drone (Project “Focus pelagic”)

4.1. Objectives:

- Assess the feasibility of estimating individual mackerel size and school size using echosounder mounted on flying drone.
- Validate estimates of individual size, fish density and school volume with stereo camera measurements and/or catch data
- Study fish behavior in large mackerel aggregations over time (several hours) using combined acoustic and stereo-camera measurements (and oxygen sensors)

Project Focus pelagic is owned by Birdview AS and financed by Innovasjon Norge.

4.2. Methods

In the survey a drone with a scientific echosounder designed and developed by Birdview AS (with assistance from IMR and Kongsberg Maritime on the acoustic package) was used (Figure 8). In addition, the vessel’s Furuno FSV25 sonar was used to monitor schools before and during capture. The plan was to first locate and monitor a mackerel school with the sonar, then fly the drone to the school and measure individual fish and combine data at school level and individual level. However, the drone is still under development and had not been tested at sea in its current form. It was also only the second time raw data were recorded with the Furuno FSV25 sonar and the first data were processed in the LSSS software, profos module for fisheries sonar data.

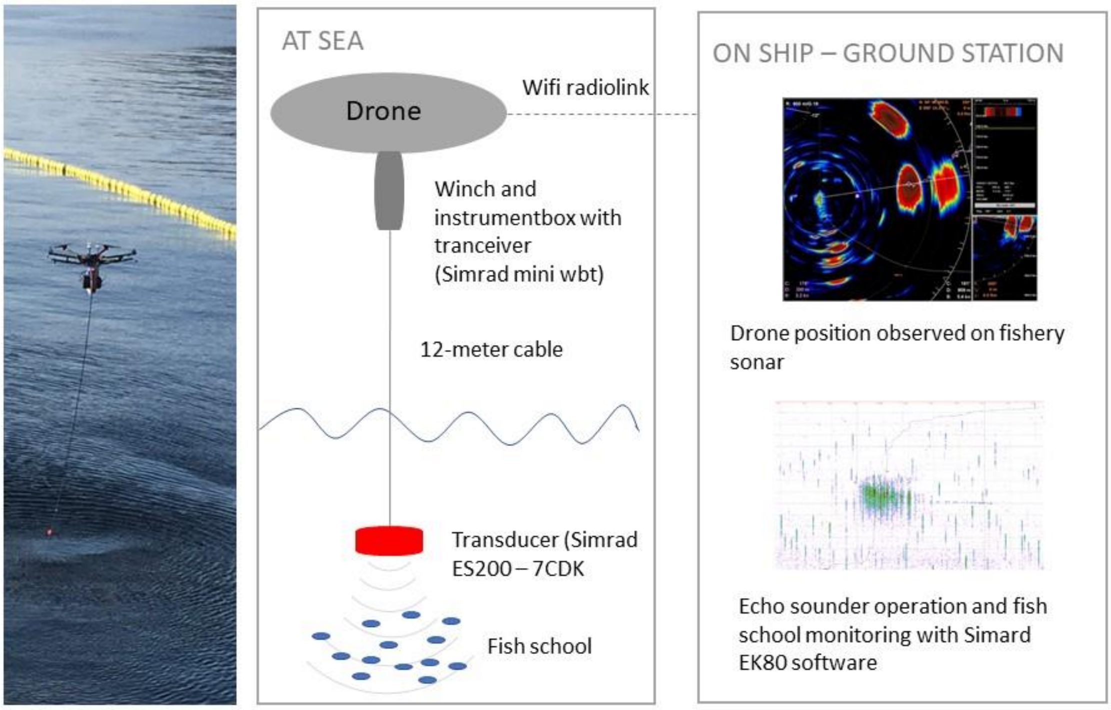


Figure 8: The planned setup with combined measurements with the drone based echosounder and sonar on board vessel.

Calibration

The echosounder (Simrad mini wbt and ES200-7CDK) was calibrated using a 38.1 mm tungsten carbide sphere (Demer et al., 2015) for the settings defined in table 4. The sonar was not calibrated because the calibration methods for the netCDF data format (Macaulay and Peña, 2018) were not ready for the survey.

Table 4. EK80 settings - flying drone

	Sizing	**Density and vertical distribution**
Pulse type	FM	CW
Pulse duration	0.512 ms	1.024 ms
Slope	Slow	N/A
Ping rate	Fast as possible	Fast as possible
Power	Try the lowest and if it gets noisy at longer ranges increase the pulse duration and power. Higher power tends to cause slower pinging on the WBAT.	Try the lowest and if it gets noisy at longer ranges increase the power. Higher power tends to cause slower pinging on the WBAT.

4.3. Preliminary Results

School monitoring

The first schools were detected on the 2nd of October about 100 nautical miles off the coast of Northern Scotland (58° 51N and 0°07 E). The mackerel were in relatively large thin concentrations. Data were collected with the Furuno FSV25 sonar as the school was encircled several times. Meanwhile the drone was prepared for take-off. The plan was to fly the drone to the same layer measured with the sonar (figure 9). The weather conditions were good, but a swell caused a considerable motion in the bow of the vessel where the take-off and landing platform was mounted. The conditions were not safe to fly with the untested drone and landing platform. The platform was a prototype, which had not previously been tested at sea, and the drone requiring manual take-off and landing. Therefore, the flight was cancelled.

Figure 9: Birdview AS drone with echosounder below is ready for takeoff. The electric winch was not working explaining why Erik Schuster sits under the platform holding the transducer.

Several mackerel schools were monitored, and data were successfully recorded with the Furuno FSV25 sonar. After one failed attempt, a school was successfully captured (cast 9; ~63.2 t).

Mackerel schools were also detected and monitored with the sonar outside Ålesund (62° 20N and 5° 28 E). The schools were at 10 – 40 m depth and swimming at a speed of 2-3.5 knots. They were reactive and dispersed when the vessel approached too close. Because of the reactive behavior of the schools, we were not able to have the drone ready and off before the schools dispersed.

Drone test flight and acoustic data quality check

Test flights with the drone were carried out close to the coast. Except for some minor problems with the electric transducer winch, the test was a success. Take-off and landing under calm sea worked well and the EK80 software was operated from the wheelhouse with good wireless contact with the drone over radio link. Electric noise was detected in the data and some attempts were made to identify the source (Fig 10). The propeller wings were removed and the echosounder was lowered into water from the vessel side and data were collected with the motors on and off. This did not remove the noise. It was concluded that the noise probably originated from the drone electronics or motor electronics being too close to the transceiver electronics. Better electromagnetic shielding around the transceiver electronics should be considered.

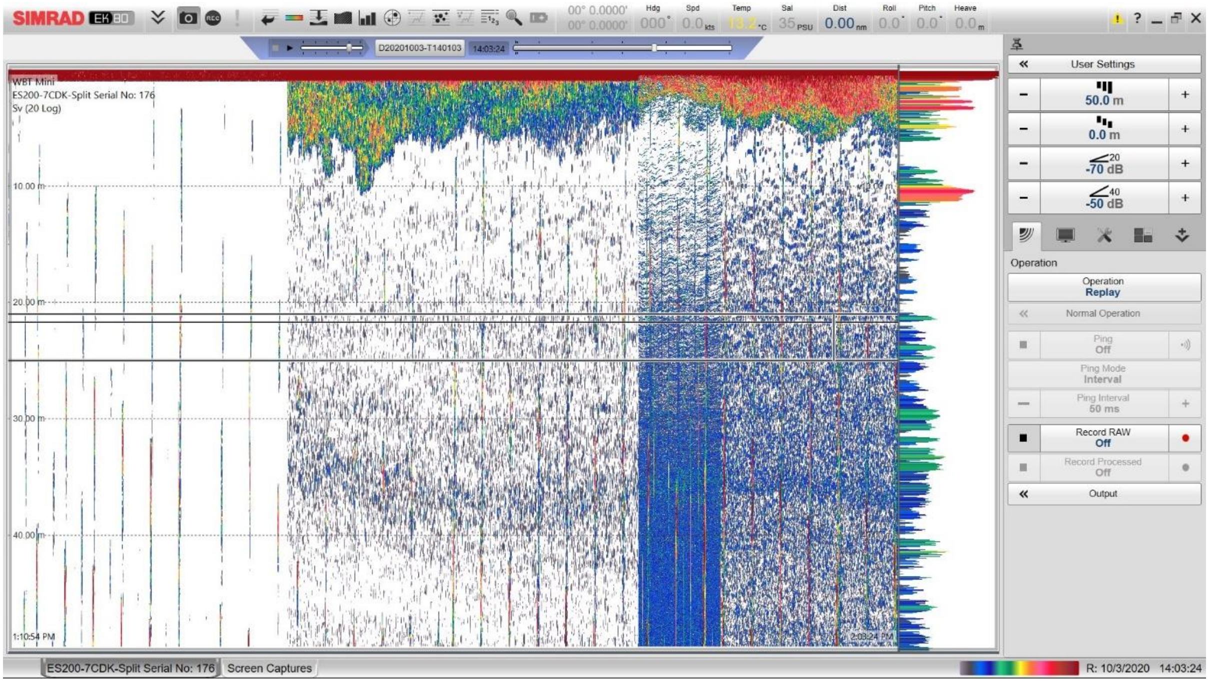
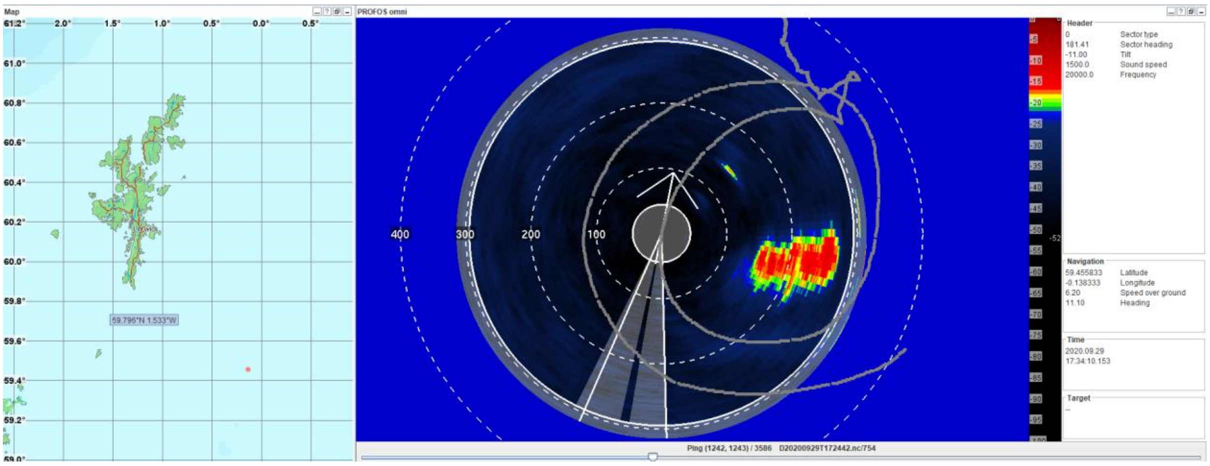


Figure 10: Data from a test flight with echosounder in passive, CW and FM mode. Interference can be seen as vertical lines and when in active mode, surface noise in the upper 5 meters.

4.4. Conclusion

The aims were ambitious for a four-day survey and were only partially achieved, as a result of time limitations, reactive school behaviour and lack of routine drone operation on board fishing boats at sea. However, the survey provided very useful tests of the drone-echosounder system, under real fishing conditions, and experience with using and recording data with the Furuno FSV25 sonar.   The sonar data collected on this survey are the first netCDF sonar data currently to be processed in the lsss profos module (Figure 11).



Header
0 Sector type
181.41 Sector heading
-11.00 Tilt
1500.0 Sound speed
20000.0 Frequency

Navigation
59.455833 Latitude
-0.138333 Longitude
6.20 Speed over ground
11.10 Heading

Time
2020.09.29
17:34:10.153

Target
--

Ping (1242, 1243) / 3586 D20200929T172442.nc/754

Figure 11: First time netCDF files are read in LSSS profos module. Before the survey IMR, Furuno Japan and CMR made a great effort to have this working.

5. Monitoring of catch and handling stressors and fish behaviour during capture

5.1. Objective

To monitor potential stressors during capture (i.e. crowding, fish to net and fish to fish contact, hypoxia and temperature change) and behavioural responses to those stressors.

5.2. Methods

IMR/HI has developed a Catch Monitoring Probe (CMP) that was deployed during various stages of the capture process: in the net; during pumping; and in the refrigerated seawater (RSW) tanks. This system comprises several instruments, in different configurations, depending on where it is deployed.

Figure 12: Catch monitoring probe (CMP) in protective housing (right) prepared for deployment from a compressed air canon (left).

When used in the net, the CMP is deployed using a pneumatic canon and comprises: a shock proof housing (to protect, support and stabilise the instruments during deployment and operation); a Sony 360 Camera (for complete contextual views around the probe); and RINKO ID oxygen, temperature & depth logger (figure 12). When used on the pump, a simpler version of the monitoring probe (containing; a RINKO ID oxygen, temperature & depth logger; and GoPro 4 camera) was attached to the vessel's catch pump, to monitor the catch during pumping; where it would be too hazardous to deploy the CMP. In the RSW tank, a RINKO ID oxygen, temperature & depth logger or a SAIV Conductivity, Temperature, Depth and Oxygen (CTDO) logger, with GoPro 4 camera attached, were lowered into the tank just prior to pumping and remained in the tank for up to 24 hours. For further discussion on the shared recirculation system for the RSW tanks on Fiskebas and its affects on temperature and dissolved oxygen measurements in linked tanks see appendix 1.

5.3. Preliminary Results & Discussion

Using multiple CMPs enables us to monitor the conditions throughout the whole capture process, as well as the fishes' responses to those conditions. Taking cast #02 as an example, the captured school of mackerel sustained an ordered schooling behaviour until late in the hauling phase (figure 13), when it started to become crowded against the netting wall and schooling behaviour breaks down (figure 14). During the hauling phase, temperature remained relatively constant but dissolved oxygen concentrations began to drop as the fish became crowded during the end of the hauling phase (Figure 15a).

Figure 13: Cast 02 [12:47:07] a view from the Nikon 360 Camera relatively late in the hauling phase showing mackerel school, close to the netting wall, which is still ordered and moderately dense.

Figure 14: Cast 02 [12:49:44] a view from the Nikon 360 Camera late in the hauling phase showing mackerel becoming locally crowding against the netting wall and starting to become disordered.

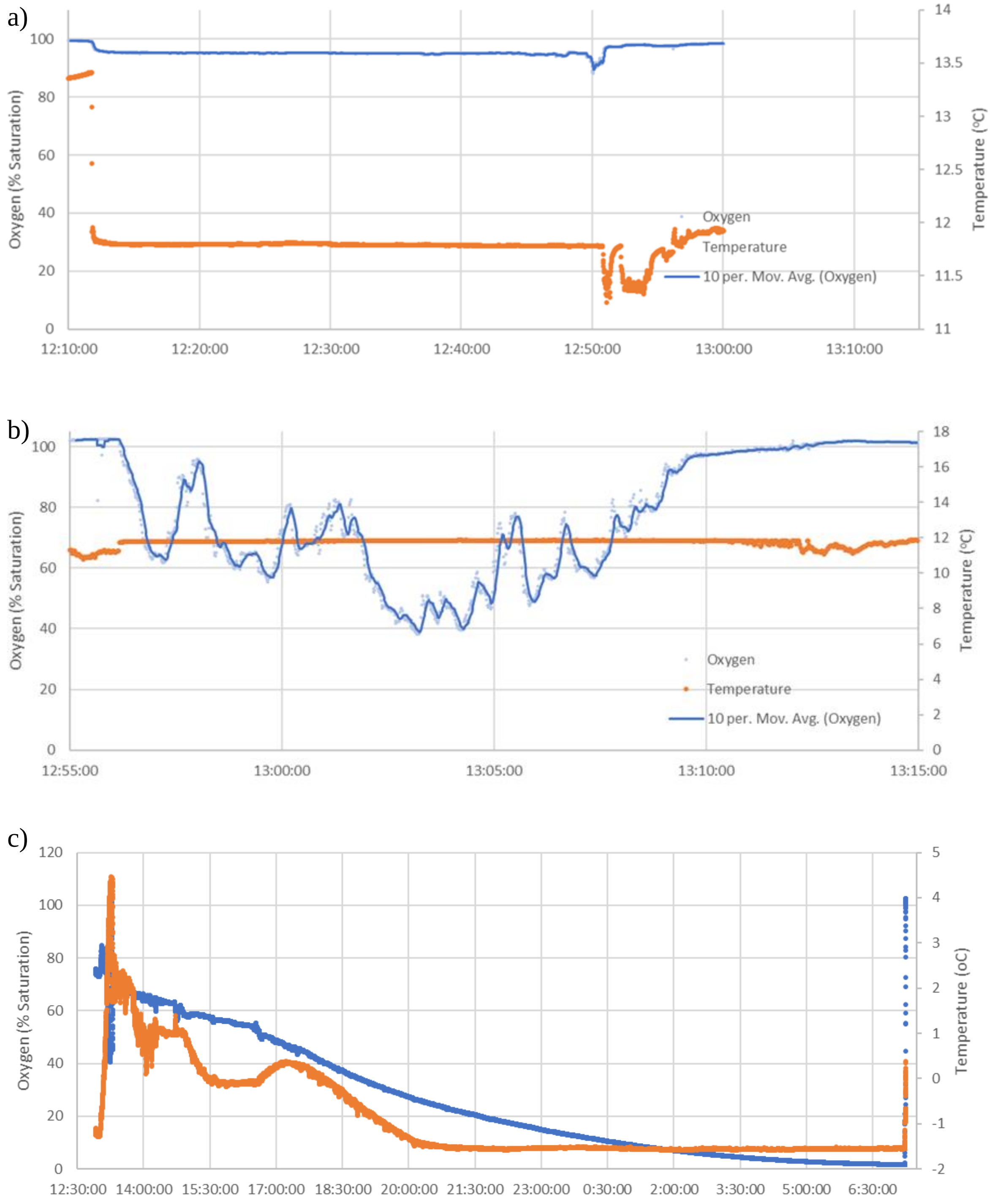


Figure 15: temperature (°C) and dissolved oxygen (% saturation) data from the CMP during different phases of capture: a) hauling; b) pumping; and c) in the RSW tank.

During the pumping phase in cast 02, water temperature remained the same (~12°C), while dissolved oxygen concentration was only moderately depleted for much of the pumping phase (i.e. >60% saturation), but with brief period of moderate hypoxic, with a minimum of 38.28% saturation (4.135mg/l), when the catch was at its most crowded (figure 15b). Mackerel behaviour was consistently disordered throughout (figure 16), but did not displayed the extremely disordered behaviour, generally referred to as "boiling", that can often be observed in pumped mackerel catches, for example in cast 03 (figure 17). "Boiling" manifests with most fish in the catch swimming displaying very rapid tail-beats, with a complete breakdown of coordination/order within the school structure. This results in many fish breaking the surface of the water, with considerable splashing; hence the colloquial term "boiling" for the behaviour. Most skipper generally prefer to avoid this response when fishing for mackerel, because it leads to premature deaths in the catch as it is pumped aboard, which they believe may affect catch quality.

Figure 16: Cast 02 [12:56:15], start of pumping phase, pump inside the catch close to the surface with mackerel demonstrating disordered behaviour.

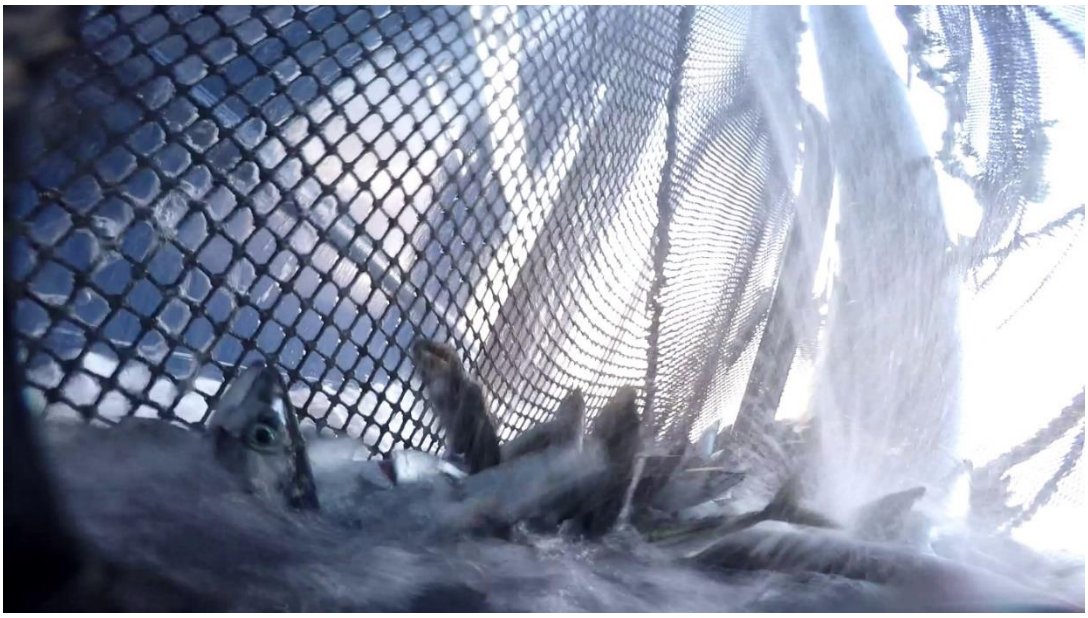


Figure 17: Cast 03 [16:17:15], end of pumping phase, pump inside the catch at the surface with mackerel demonstrating extremely disordered behaviour ("boiling").

The oxygen minimum during hauling in the net, and particularly during pumping, appears to be correlated with catch size (figure 18). Interestingly, the relationship between catch size and minimum oxygen concentration in herring catches shows a greater oxygen depletion for comparable catch sizes. The Fiskebas skipper and crew stated that they deliberately try to avoid over-crowding mackerel during pumping, and this difference in oxygen minima for comparable catch sizes may be supporting evidence of this practice.

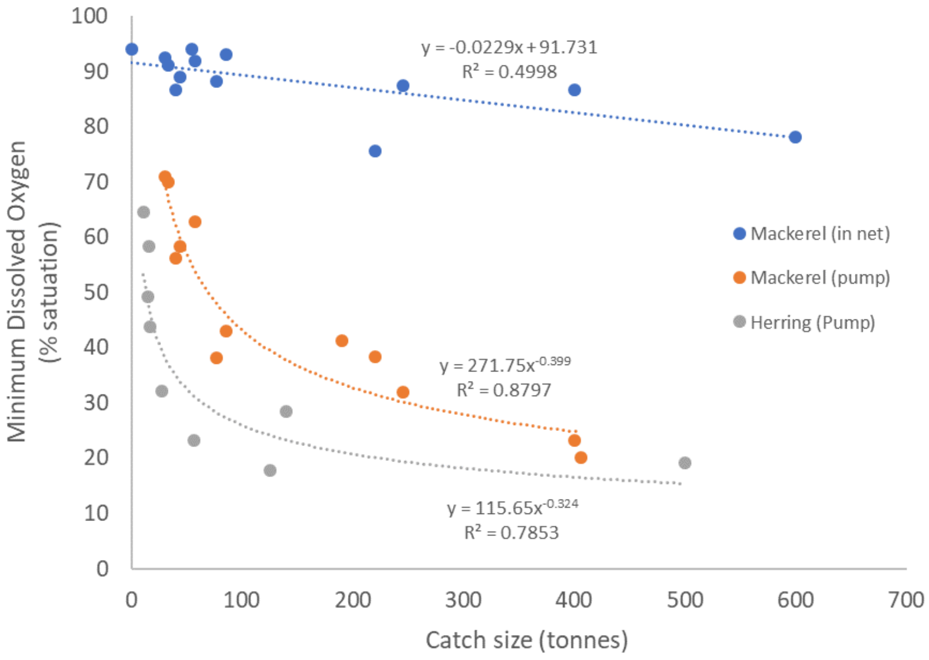


Figure 18 – minimum dissolved oxygen concentrations (% saturation) in relation to catch size of mackerel during the hauling and pumping phases (From cruises Fiskebas # 2019832, # 2021823 & # 2020851). Also included is data from herring catches during pumping (Vendla, Tokt # 2019833 & Fiskebas # 2020851).

Finally, on entering the RSW tank the fish experienced a very rapid temperature drop to around 2°C (from ~12°C). There was some fluctuation in temperature during the pumping phase, as more catch was added, but this generally stabilised at -1.5°C within 6 hours of completion of pumping. There was a relatively slow, but steady, decline in dissolved oxygen in the tank; reaching approximately 40% saturation about 5 hours after pumping was completed. From this point the oxygen depletion continued a slow depletion to a minimum of 1.6 % saturation after ~18 hours of observation (when the oxygen logger was removed). Behavioural observations of fish in the RSW tank were not possible from video observations due to blood in the water limiting visibility. However, the behaviour of fish sampled from the RSW tank was observed during the vitality assessments (see section 6).

Work will continue on this data to quantify behaviour during the capture process with respect to several metrics, including: crowding, collective behaviour (school order; frequency of turns); individual activity levels (tail beat frequency); fish-to-net contact. These will be correlated with relevant stressors/explanatory variables: hauling time, length of net hauled, catch size, oxygen concentration.

6. Effect of capture and handling stress on catch vitality and welfare

6.1. Objective

to determine the stress- (or welfare-) status of the catch at different stages of the capture process using vitality assessments.

6.2. Methods

In addition to monitoring the behaviour of fish in the catch (see above), on this tokt we also used a suite of behaviours/reflexes to monitor the "vitality" of individual fish sampled from the catch after pumping from the net and for sub-samples taken from the RSW tanks at various times after pumping.

"Vitality" is an objective measure of how alive an animal is, or conversely how close to death it is. Its objective measurement relies on using a selection of behavioural metrics, or reflexes, that can reliably indicate their ability to respond to a range of different stimuli, both contextual and physical. In this assessment, nine different metrics were used; 5 free swimming observations (in an observation tank) and 4 observations while handling (see table 5).

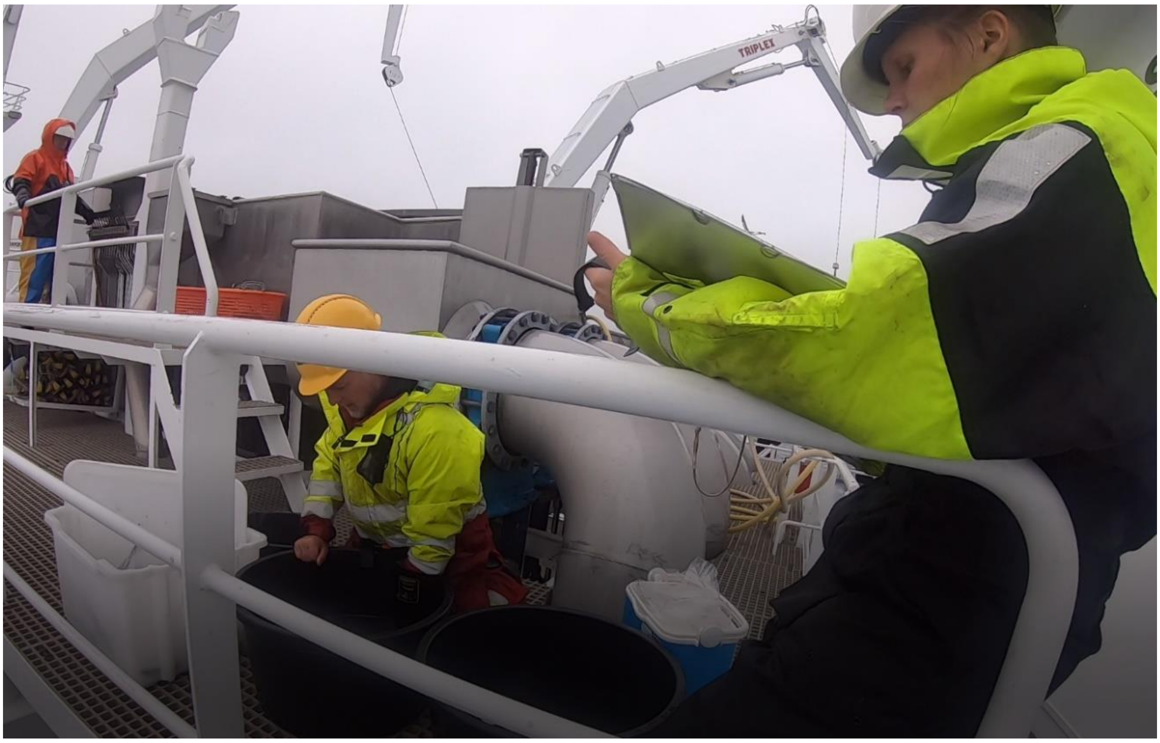


Figure 19 – mackerel are examined after sub-sampling from pump dewatering grid (in background).

Table 5 – Summary of vitality metrics used for mackerel sub-sampled from the pump and RSW tanks.

	Test	Positive Response	Negative implications (i.e. response absent or weak)
Free Swimming Observations			
Evasion 1	Fish transfered from net into observation tank	A "startle" response, or swims around tank seeking "escape".	Fish lacks awareness of substantial change in environment. Or is unable to respond due to exhaustion, or physical injury.
Orientation / Self-righting	Fish transfered from net into observation tank	Can self-orientate dorsal side up within 5 seconds of transfer.	Fish has lost a basic reflex - balance. Therefore, swimming and avoidance of potential threats will be severely compromised.
Head Complex	Fish transfered from net into observation tank	A coordinated and regular use of mouth and operaculae - indicative of normal respiration (> 1 per 10 sec).	Absence - respiratory failure, fish is dead or close to death. Very strong - fish may be hypoxic or fatigued.
Evasion 2	Observer's hand, in water, approaches fish from side; in preparation for "caudal reflex test (see below).	A "startle" response, or swims around tank seeking "escape".	Fish lacks awareness of potential visible threat. Or is unable to respond due to exhaustion, or physical injury.
Caudal Reflex	Observer touches, or attempts to hold, caudal fin.	Fish immediately (<1 sec) attempts to swim away from physical contact.	Fish lacks awareness of potential physical threat. Or is unable to respond due to exhaustion, or physical injury.
Observations While Handling			
Body Flex 1 - Restrained	Observer hold fish firmly in clenched hand, with thumb and fore-finger just posterior of operculae.	Fish should flex its tail musculatur in an attempt to escape (< 3 sec). [NB - test starts in water, as observer attempts to remove fish from tank].	Fish lacks awareness of strong physical threat (i.e. restraining). Or is unable to respond due to exhaustion, or physical injury.
Vestibulo-ocular response	Observer - while holding fish as above - rotates fish on the longitudinal axis.	Fish should attempt to hold eye steady, with respect to horizonal. That is, looking from the posterior, the eye should appear to look down, as the head is rotated clockwise; and *vice versa* .	Fish has lost a basic reflex - balance. May indicate loss of functionality in brain stem.
Mouth Closure	Observer - while holding fish as above - uses finger to open open fish's mouth.	Fish should attempt to resist opening action. May also respond with a "head-complex motion" and/or "body flex" (< 3 sec).	Fish lacks awareness of an intrusive physical threat. Or is unable to respond due to exhaustion, or physical injury.
Body Flex 2 - Flat surface	Fish is laid, unrestrained, on a flat surface.	Fish should flex its tail musculatur (< 3 sec).	Fish lacks awareness of substantial change in physical status - i.e. released but emersed. Or is unable to respond due to exhaustion, or physical injury.

In addition to vitality metrics, a sub-sample of mackerel had blood samples taken (via caudal puncture), which were analysed on site for blood lactate using the Lactate Pro 2 (Arkray Inc., Kyoto, Japan) point-of-care (POC) analyser.

When sub-sampling from the RSW Tank, fish were collected using a purposely made sampling net, supported on a stainless-steel ring (Ø = 0.8m). At each sampling period (see table 6), two sub-samples were taken: A) from fish swimming or floating in the water column above the bottom of the tank; and B) from the bottom of tank, with a ~5kg weight attached to one side of the ring of the sampling net to ensure it penetrated any layer of fish collecting on the bottom of the tank. When sampling for fish swimming or floating in the water column, the number of fish per haul with the sampling net was noted (as an indicator of relative density; i.e. catch per unit effort). When five consecutive samples had zero fish sampling was abandoned, based on the assumption that all fish were on the bottom of the tank. In addition, the depth of the tank was measured at each sampling period to determine the proportion of the catch that had accumulated on the bottom of the tank over time.

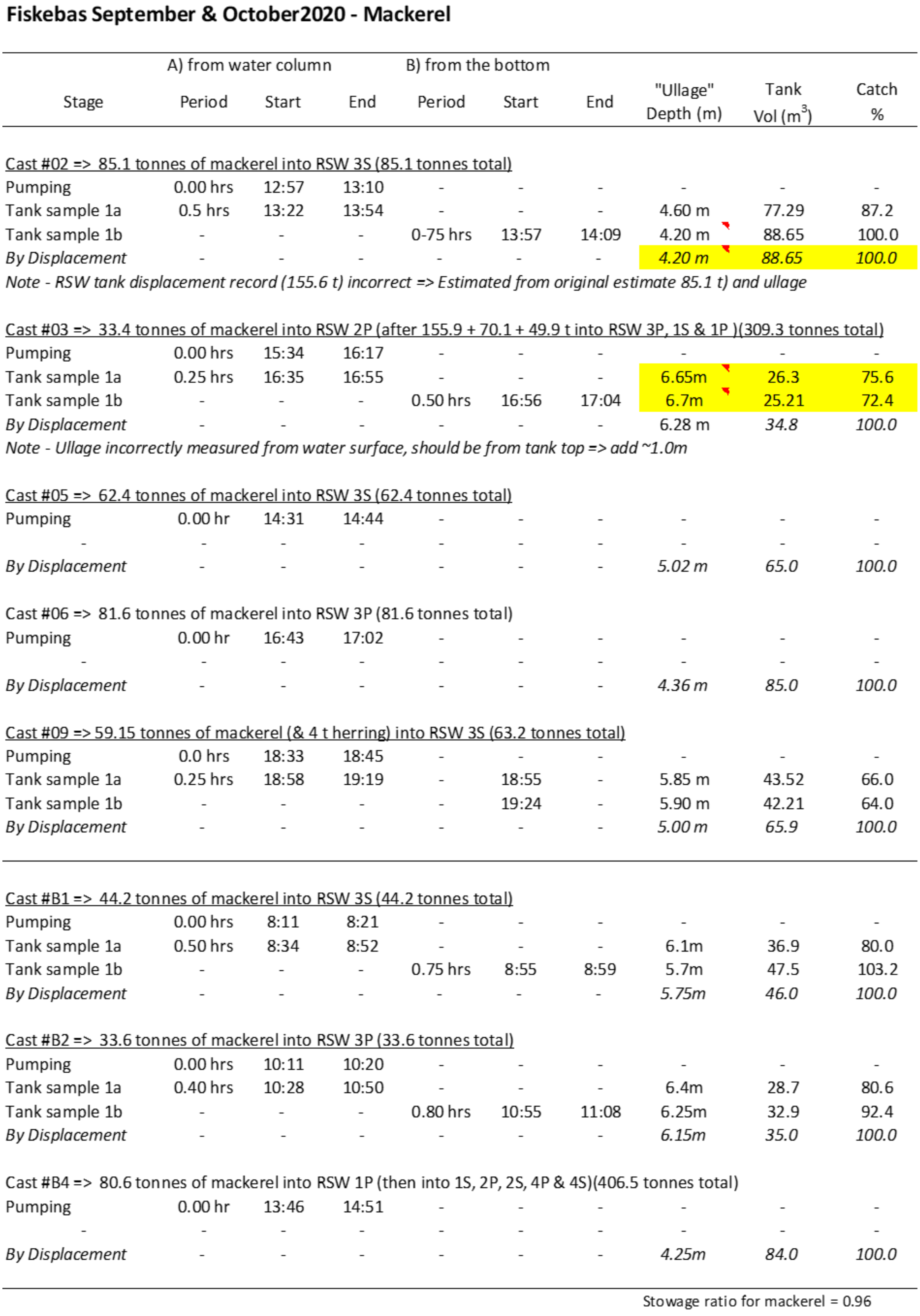
6.3. Preliminary Results & Discussion

Vitality scores during pumping generally declined over time, with the catches' increasing exposure to crowding and hypoxic conditions (figure 20 a, b & c). However, this pattern was disrupted in large catches, where the oxygen saturation drops substantially below "safe thresholds" (i.e. 40% saturation; Handegard et al, 2017, Breen et al, 2020), when low vitality was observed in samples several minutes after the hypoxic event (i.e. oxygen min), followed a brief period of recovery. In addition, in some casts, there appeared to be a drop in mean vitality and/or an increase in variance associated with the end of pumping, specifically when the net was hauled close in; as indicated by a substantial reduction in the pump depth ((e.g. casts 03 & B4, figure 20 c & d). Preliminary analysis of the blood lactate data suggests an inverse correlation with vitality, with high lactate concentrations generally being associated with low vitality (figure 20).

In the RSW tanks, there were two distinct sub-components of fish in the tank: A) fish swimming or floating in the water column above the bottom of the tank; and B) fish laying on the bottom of the tank. From depth measurements, it appears that most mackerel after entering the tank quickly (<30 mins) sank to the bottom of the RSW tank to become part of subcomponent B (see table 6). However, a small proportion did remain in sub-component A during this period and appeared to be conscious, despite the low water temperature and reduced dissolved oxygen concentrations (see examples in figure 21), although they had a significantly reduced mean vitality and raised blood lactate concentrations compared to mackerel during pumping. Fish on the bottom of the tank (subcomponent B) generally had zero vitality scores. From observations on previous cruises, it appears that after a period of ~1 hour, all mackerel sank to the bottom of the tank and consistently had a zero-vitality score. Therefore, no further samples were taken before 1 hour on this cruise. The analysis of this data will continue with the aim of establishing the likely cause of death of the mackerel in the

RSW tanks (i.e. temperature shock versus hypoxia), in comparison to herring observed in cruises 2019833 and 2020851.

Table 6 – Summary of Vitality Assessments and RSW Ullage, by Cast.



Fiskebas September & October2020 - Mackerel

	A) from water column			B) from the bottom					
Stage	Period	Start	End	Period	Start	End	"Ullage" Depth (m)	Tank Vol (m^3)	Catch %
Cast #02 => 85.1 tonnes of mackerel into RSW 3S (85.1 tonnes total)									
Pumping	0.00 hrs	12:57	13:10	-	-	-	-	-	-
Tank sample 1a	0.5 hrs	13:22	13:54	-	-	-	4.60 m	77.29	87.2
Tank sample 1b	-	-	-	0-75 hrs	13:57	14:09	4.20 m	88.65	100.0
By Displacement	-	-	-	-	-	-	*4.20 m*	*88.65*	*100.0*
Note - RSW tank displacement record (155.6 t) incorrect => Estimated from original estimate 85.1 t) and ullage									
Cast #03 => 33.4 tonnes of mackerel into RSW 2P (after 155.9 + 70.1 + 49.9 t into RSW 3P, 1S & 1P)(309.3 tonnes total)									
Pumping	0.00 hrs	15:34	16:17	-	-	-	-	-	-
Tank sample 1a	0.25 hrs	16:35	16:55	-	-	-	6.65m	26.3	75.6
Tank sample 1b	-	-	-	0.50 hrs	16:56	17:04	6.7m	25.21	72.4
By Displacement	-	-	-	-	-	-	6.28 m	*34.8*	*100.0*
Note - Ullage incorrectly measured from water surface, should be from tank top => add ~1.0m									
Cast #05 => 62.4 tonnes of mackerel into RSW 3S (62.4 tonnes total)									
Pumping	0.00 hr	14:31	14:44	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
By Displacement	-	-	-	-	-	-	*5.02 m*	*65.0*	*100.0*
Cast #06 => 81.6 tonnes of mackerel into RSW 3P (81.6 tonnes total)									
Pumping	0.00 hr	16:43	17:02	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
By Displacement	-	-	-	-	-	-	*4.36 m*	*85.0*	*100.0*
Cast #09 => 59.15 tonnes of mackerel (& 4 t herring) into RSW 3S (63.2 tonnes total)									
Pumping	0.0 hrs	18:33	18:45	-	-	-	-	-	-
Tank sample 1a	0.25 hrs	18:58	19:19	-	18:55	-	5.85 m	43.52	66.0
Tank sample 1b	-	-	-	-	19:24	-	5.90 m	42.21	64.0
By Displacement	-	-	-	-	-	-	*5.00 m*	*65.9*	*100.0*
Cast #B1 => 44.2 tonnes of mackerel into RSW 3S (44.2 tonnes total)									
Pumping	0.00 hrs	8:11	8:21	-	-	-	-	-	-
Tank sample 1a	0.50 hrs	8:34	8:52	-	-	-	6.1m	36.9	80.0
Tank sample 1b	-	-	-	0.75 hrs	8:55	8:59	5.7m	47.5	103.2
By Displacement	-	-	-	-	-	-	*5.75m*	*46.0*	*100.0*
Cast #B2 => 33.6 tonnes of mackerel into RSW 3P (33.6 tonnes total)									
Pumping	0.00 hrs	10:11	10:20	-	-	-	-	-	-
Tank sample 1a	0.40 hrs	10:28	10:50	-	-	-	6.4m	28.7	80.6
Tank sample 1b	-	-	-	0.80 hrs	10:55	11:08	6.25m	32.9	92.4
By Displacement	-	-	-	-	-	-	*6.15m*	*35.0*	*100.0*
Cast #B4 => 80.6 tonnes of mackerel into RSW 1P (then into 1S, 2P, 2S, 4P & 4S)(406.5 tonnes total)									
Pumping	0.00 hr	13:46	14:51	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
By Displacement	-	-	-	-	-	-	*4.25m*	*84.0*	*100.0*

Stowage ratio for mackerel = 0.96

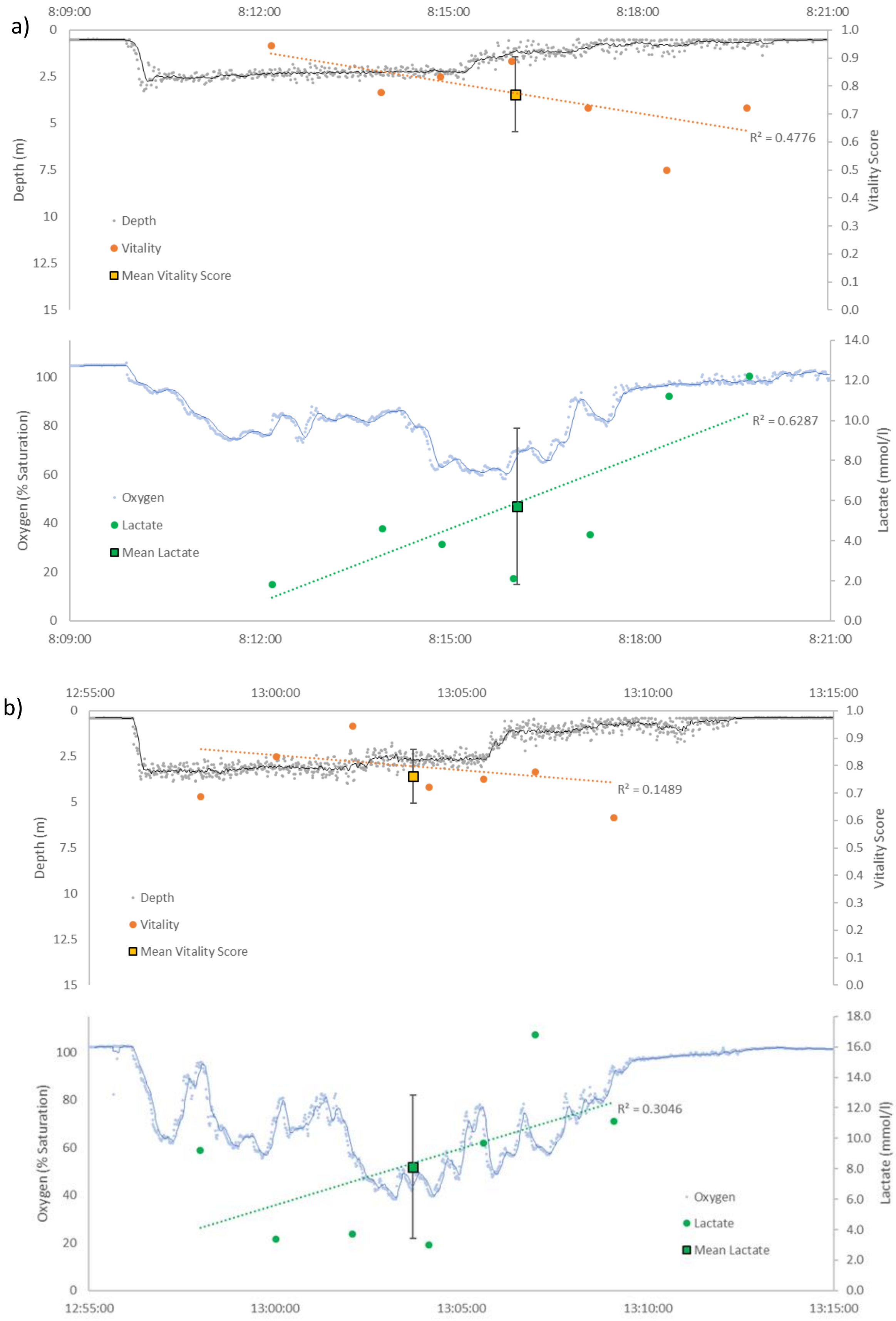


Figure 20 a & b: Vitality scores and CMP (pump) depth (m) over time (upper panel) and blood lactate, with dissolved oxygen concentration (% saturation) in water (lower panel), during pumping in two different casts: a) cast #B1 (44.2 tonnes); b) cast #B2 (85.1 tonnes). Mean values (& 95% confidence intervals) are shown for subsamples of the catch destined for different RSW tanks.

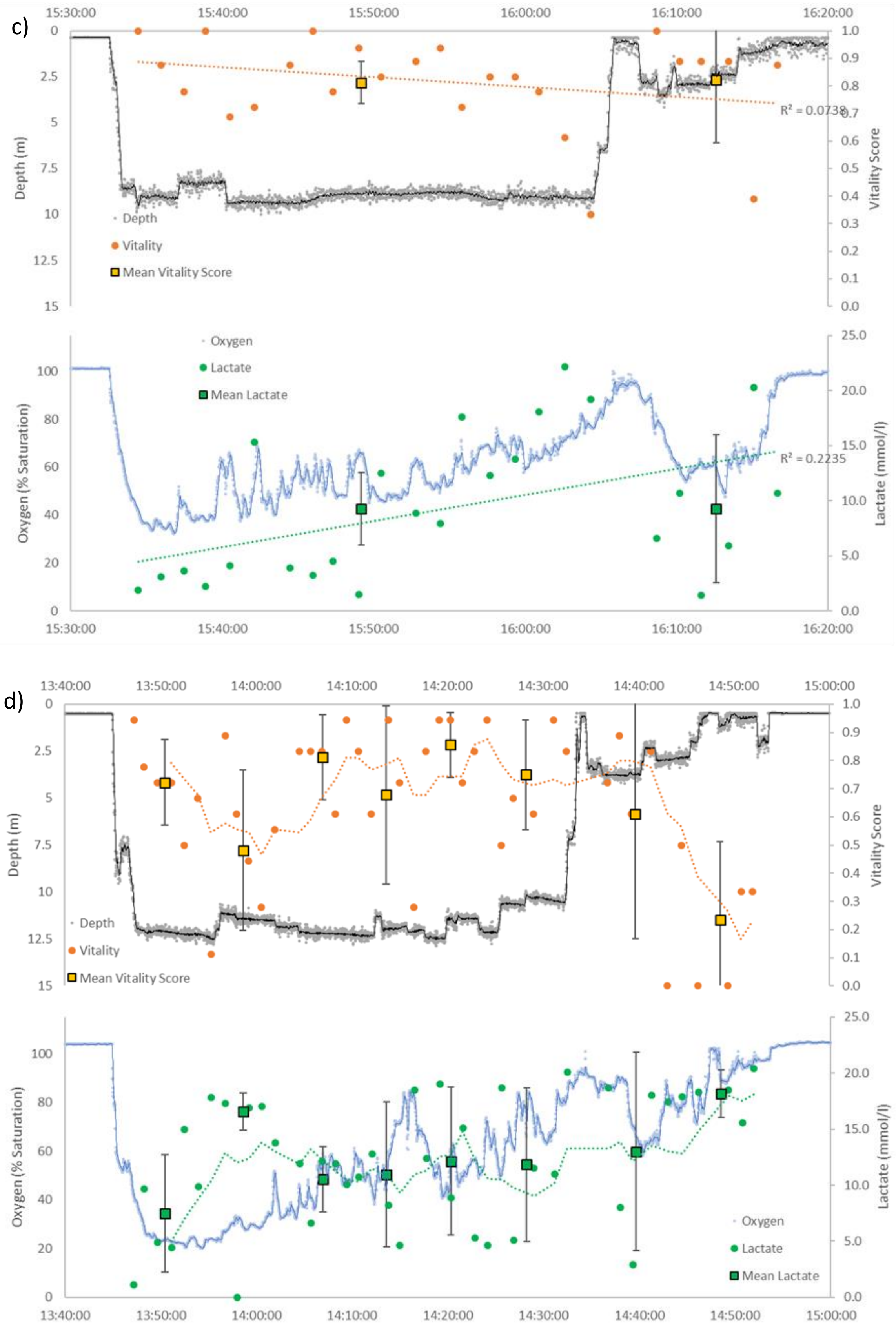


Figure 20 c & d: Vitality scores and CMP (pump) depth (m) over time (upper panel) and blood lactate, with dissolved oxygen concentration (% saturation) in water (lower panel), during pumping in two different casts: c) cast #03 (309.3 tonnes); d) cast #B4 (406.5 tonnes). Mean values (& 95% confidence intervals) are shown for subsamples of the catch destined for different RSW tanks.

a)

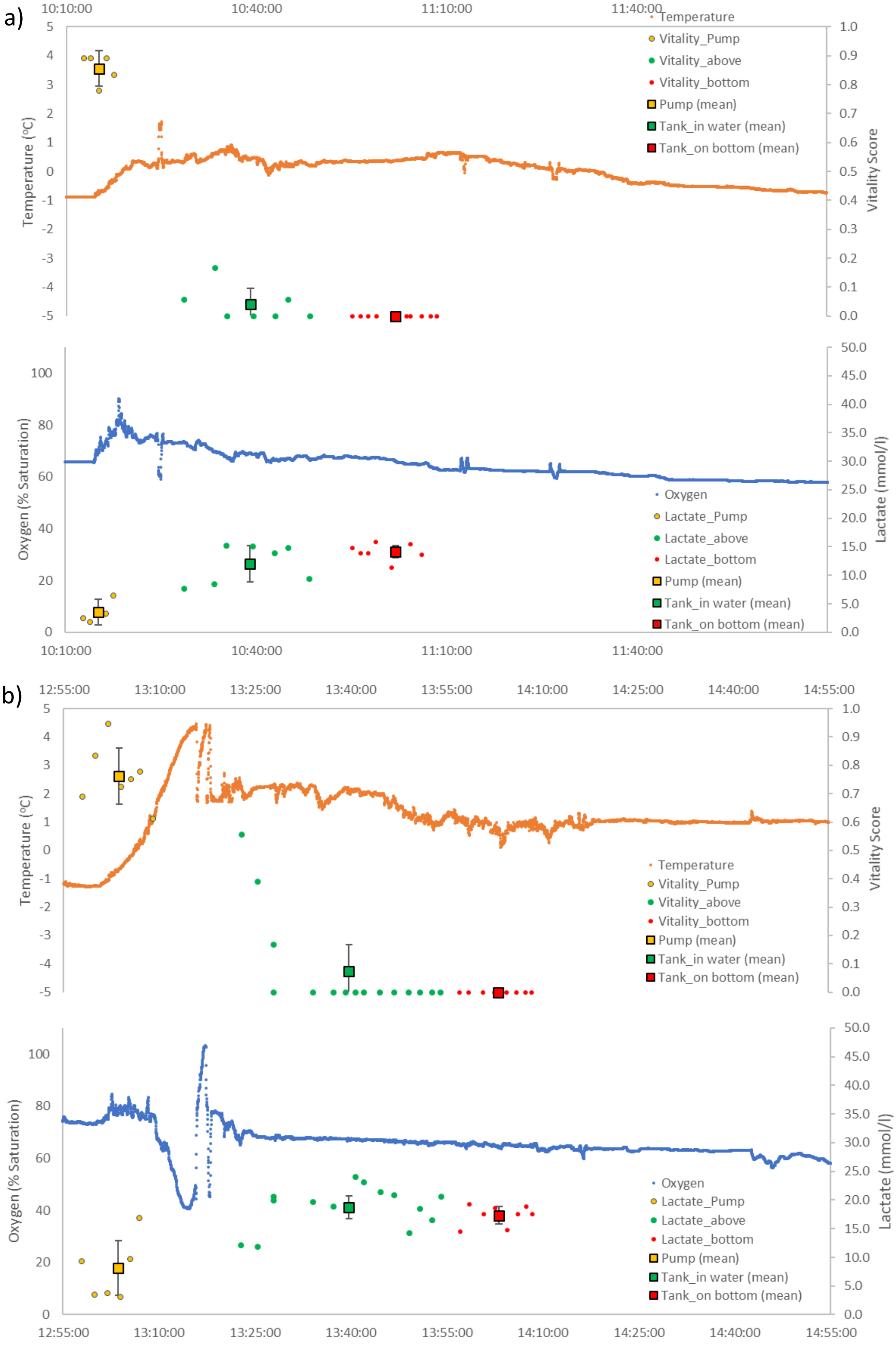


Figure 21 a & b: Vitality scores and water temperature (ºC) over time (upper panel) and blood lactate, with dissolved oxygen concentration (% saturation) (lower panel), in the RSW tanks during and after pumping in two different casts: a) cast #B2 (33.6 tonnes); b) cast #02 (85.1 tonnes). Mean values (& 95% confidence intervals) are shown for subsamples of the catch destined for different RSW tanks.

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Acknowledgements.

This cruise was jointly funded by the Norwegian Seafood Research Fund [*Fiskeri- og havbruksnæringens forskningsfinansiering; FHF*] and the Institute of Marine Research (IMR) as part of the «Catch control in seine fishing for pelagic species" [*Fangstkontroll i notfiske etter pelagiske arter*; FHF project number 901350]. Project Focus Pelagic is owned by Birdview AS and financed by Innovasjon Norge. The project and authors are also grateful to the government and authorities of the United Kingdom for granting permission to conduct this research in their territorial waters.

The authors are very grateful to the skipper (Geir Madsen) and crew of MF Fiskebas, who were very supportive and resourceful throughout the cruise. We thank Thor Bærhaugen, Ivar Wangen and Simrad for cooperation, loans and equipment and guidance, and our colleague Shale Rosen for the loan of camera equipment.

Finally, our thanks to the managers and staff of Birdview and Mohn Drilling for their constructive cooperation during the preparation and execution of the drone and ROV trials.

Appendix A: RSW Comparison Trials

Background

The refrigerated seawater (RSW) tanks on board FV Fiskebas have a shared circulation system, as do many vessels in the pelagic fleet. Therefore, it would be informative to understand how the conditions in the RSW tanks changed as more catch was sequentially added and what interactions there were between temperature and oxygen measurements in the linked tanks. That is, understanding the linkage between tanks will help explain non-regular changes in temperature and dissolved oxygen.

Objective

Use the Rinko oxygen/temperature loggers to monitor changing conditions in the RSW tanks, due to the sequential addition of catches from several casts.

Methods

The nine tanks aboard can be linked as either one continuous circulating system or two separate circulating systems: forward (RSWs 2P, 2S, 1P, [1C] & 1S) and aft (RSWs 3P, 3S, 4P and 4S) (figure A1). The usual practice is to operate two separate circulating systems, usually filling the aft tanks first, and using the forward tanks as a reserve. Note – RSW 1C, the forward central tank, is rarely used or filled, because of adverse effects on the trim of the boat.

Standard monitoring of dissolved oxygen and water temperature in an RSW tank in this project uses a RINKO ID oxygen, temperature & depth logger or a SAIV Conductivity, Temperature, Depth and Oxygen (CTDO) logger (sometimes a with GoPro 4 camera attached). These are generally lowered into the tank just prior to pumping and can remain in the tank for up to 24 hours.

During this trial, RINKO's were already in RSW 3S (cast #01) and RSW 3P (cast #2) as part of the vitality monitoring of those catches. After cast #04, at ~18:15 two additional RINKOs were deployed in RSW 4S & 4P. The aim was to deploy the RINKO loggers at comparable depths: ~4m. However, the RINKO in RSW 4P appears to have been snagged only deployed to ~1.8m, which was only apparent after the data had been downloaded. In addition, the unit in RSW 4S shut down prematurely at ~22:36 due to a battery failure.

Preliminary Results and Discussion

Table A1 describes the status of the RSW tanks after each cast, on 16th October 2020, with respect to contents (water and catch) and estimated exchange rates of the residual water in each tank.

Table A1 – RSW tank status after each cast, with respect to contents (water and catch) and estimated exchange rates of the residual water in each tank.

After Cast #1 - note only RSW 3S & 3P filled with SW

Tank	**Logger**	in	out	**Cast**	**Pumping Time (UTC)**		**Tank details**	**Tank Contents**		Tank Water Volume		Residual	Exchange rate per tank		
	ID #	16-Oct-20	17-Oct-20		Start	Stop	Volume (m^3)	Fish (t)	Density (t/m^3)	Displaced	Residual	ratio in tank	m^3/hr	avail.vol/hr	hr/tank
RSW_3S	0048	7:56	11:50	1	8:12	8:21	177	44.2	0.250	46.04	130.96	0.74	270.00	2.06	0.49
RSW_4S	0050	16:18	11:52												
RSW_4P	0049	16:18	12:03												
RSW_3P	0056	10:02	12:01				177			0.00	177.00	1.00	270.00	1.53	0.66
Total							354	44.2		46.04	307.96	0.87	540.00	1.75	0.57

After Cast #2 - note only RSW 3S & 3P filled with SW

Tank	**Logger**	in	out	**Cast**	**Pumping Time (UTC)**		**Tank details**			Tank Water Volume		Residual	Exchange rate per tank		
	ID #	16-Oct-20	17-Oct-20		Start	Stop	Volume (m^3)	Contents (t)	Density (t/m^3)	Displaced	Residual	ratio in tank	m^3/hr	avail.vol/hr	hr/tank
RSW_3S	0048	7:56	11:50	1	8:12	8:21	177	44.2	0.250	46.04	130.96	0.74	270.00	2.06	0.49
RSW_4S	0050	16:18	11:52												
RSW_4P	0049	16:18	12:03												
RSW_3P	0056	10:02	12:01	2	10:11	10:20	177	33.6	0.190	35.00	142.00	0.80	270.00	1.90	0.53
Total							354	77.8		81.04	272.96	0.77	540.00	1.98	0.51

After Cast #4 - note RSW 3S & 3P now filled with chilled SW from forward tanks

Tank	**Logger**	in	out	**Cast**	**Pumping Time (UTC)**		**Tank details**			Tank Water Volume		Residual	Exchange rate per tank		
	ID #	16-Oct-20	17-Oct-20		Start	Stop	Volume (m^3)	Contents (t)	Density (t/m^3)	Displaced	Residual	ratio in tank	m^3/hr	avail.vol/hr	hr/tank
RSW_3S	0048	7:56	11:50	1	8:12	8:21	177	44.2	0.250	46.04	130.96	0.74	150.00	1.15	0.87
RSW_4S	0050	16:18	11:52	4	13:46	14:51	139	19.2	0.138	20.00	119.00	0.86	150.00	1.26	0.79
RSW_4P	0049	16:18	12:03	4	13:46	14:51	140	50.9	0.364	53.02	86.98	0.62	150.00	1.72	0.58
RSW_3P	0056	10:02	12:01	2	10:11	10:20	177	33.6	0.190	35.00	142.00	0.80	150.00	1.06	0.95
Total							633	147.9		154.06	478.94	0.76	600.00	1.25	0.80

Displaced volume = catch wieght (t) / displacment correction factor
Displacment correction factor: mackerel = 0.96; herring = 0.93.
Exchange rate (m^3/hr) is limited to 90% capacity when not all tanks use

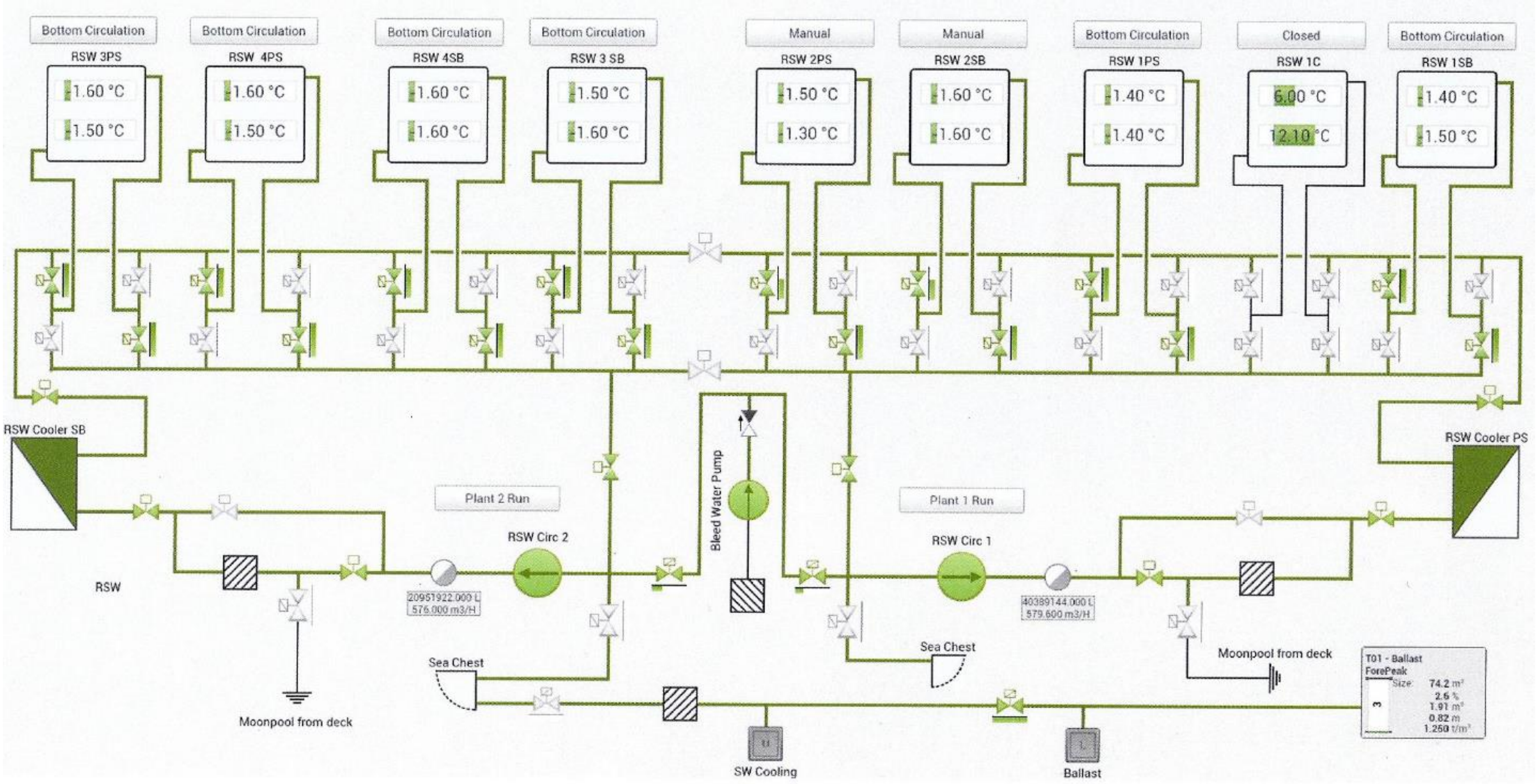

Figure A1 – Schematic plan of the Refrigerated Seawater (RSW) tank recirculation system on FV Fiskebas.

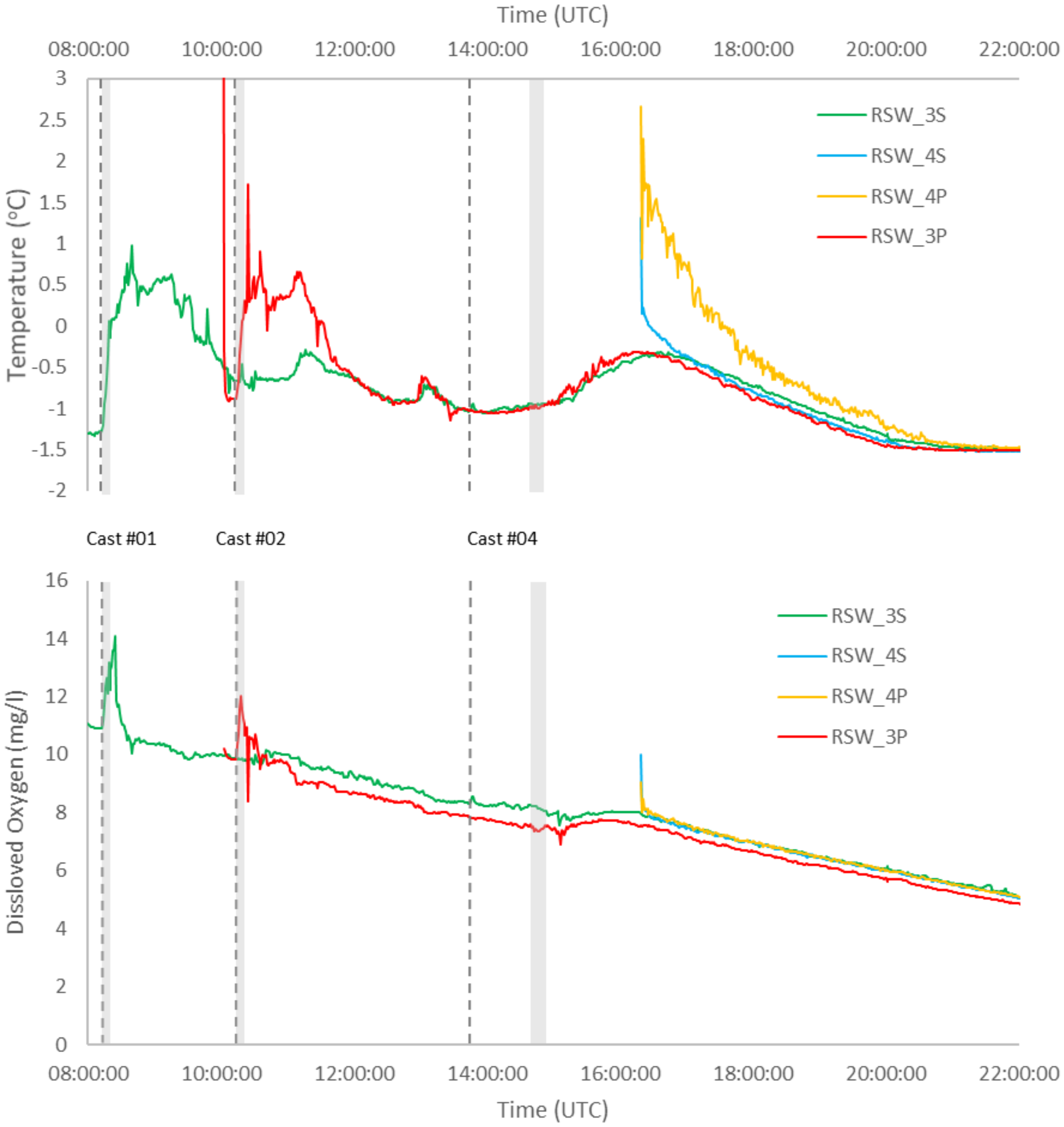

Figure A2 – Changes in water temperature (ºC) (top) and dissolved oxygen (mg/l) (bottom) in four refrigerated seawater storage tanks (RSWs) during and after being filled with a mackerel from a purse seine catches from 3 separate casts (see table A1). RSWs 3S and 3P were monitored from just before being filled from casts #01 and #02, respectively, while RSWs 4S ad 4P were monitored post-filling (from ~1615), both from cast #04. Vertical dashed lines indicate when pumping operations began and grey shaded boxes are the periods when the RSW tanks were being filled.

RSW 3S, which had a total capacity of 177m^3, was filled with 44.2 tonnes of mackerel from cast #01 between 08:12 and 08:21 (UTC). This catch displaced 46.04 m^3 of water from the tank, leaving a residual capacity of 130.96 m^3 of chilled water mixed with the catch. At that time, RSW 3S was connected to only one other tank within the recirculation system, RSW 3P (also with a total capacity of 177m^3). The circulation pump at this time was assumed to be operating at ~90% of full capacity (540 m^3/hr; 270 m^3/hour/tank), because it was only circulating water in two tanks (Chief Engineer, Fiskebas, pers. comm.). Therefore, for RSW 3P (without any catch), the pump could circulate the available volume of water in the tank (177

m^3) approximately 1.53 times every hour, meaning the water in the tank could be completely exchanged in ~0.66 hours. RSW 3S, because of the catch, had less available water to exchanged (130.96m^3), therefore this residual water volume could be exchanged in only 0.49 hours, i.e. 2.06 times every hour.

During this time, tank RSW 3S was being monitored using a RINKO oxygen/temperature logger (#0048), which had been setup up in the tank at 07:56 at a depth of ~3.6m. During pumping, while the tank was being filled with catch, the water temperature rose rapidly from approximately -1.25°C to ~0°C, as the incoming catch (including some entrained water) began to displace some water and warm the residual contents of the tank. Immediately after pumping, the water temperature continued to rise, at a slower rate, until it peaked at ~08:40 at a temperature of 0.98°C. After this, the water temperature began to cool but in an irregular pattern, presumably due to heterogenous mixing of water masses within the tank and/or inconsistent water exchange rates within the recirculation system. By 10:15 (just prior to cast #02 being pumped aboard) the water temperature had cooled to approximately -0.8°C.

Over the same period, dissolved oxygen concentration in RSW 3S, rose from 10.89mg/l to ~12mg/l during pumping, to a maximum of ~14.1mg/l at 08:25. After this there was a very rapid decline in oxygen concentration, presumably as the resident catch began to respire the available dissolved oxygen, to a minimum of ~10.0mg/l at ~08:40 (coinciding with the peak in temperature). It is assumed at this time the tank recirculation system was activated, when chilled and oxygenated water from RSW 3P began to enter RSW 3S and arrest the temperature rise, as well as moderate the declination rate of dissolve oxygen concentration. The dissolved oxygen concentration continued to decline, at a slower rate, until just prior to RSW 3P being filled with catch from cast #02 at 10:11.

RINKO oxygen/temperature logger (#0056) was setup in RSW 3P at 10:02, at a depth of ~4.0m, just before the tank was filled with catch from cast #02 at 10:11. At 10:10, RSW 3S and 3P had temperature difference of ~0.25°C, with RSW 3P being the colder at -0.89°C. At the same time, there was an apparent difference of only 0.03 mg/l in dissolved oxygen concentration between the two tanks; although it is suspected that in reality RSW 3P was likely to have had a slightly higher dissolved oxygen concentration because of a small calibration offset between RINKO #0056 and the other loggers (see below).

RSW 3P was filled with 33.6 tonnes of mackerel from cast #02, between 10:11 and 10:20. This displaced 35.0 m^3 of water, leaving a residual water volume of 142 m^3. At an assumed exchange rate of 540 m^3/hr (270 m^3/tr/tank), this residual water mass could be exchanged 1.9 times per hour, i.e. taking ~0.53 hours to completely exchange the residual water mass. As with RSW 3S, the water temperature increased rapidly during filling from approximately minus 0.9°C to approximately 0.3°C, with a further rapid increase to 1.72°C at 19:25 in the minutes following pumping. This was followed initially by a rapid drop and then an irregular decline in water temperature over the next 3.5 hours. Although irregular in pattern, rises and falls in temperature were correlated between the two tanks. Moreover, the water temperatures in RSW 3S and 3P converged at minus 0.59°C at approximately 12:04, and remained converged (with some minor deviations of <0.25°C) for the remainder of the monitoring period.

Dissolved oxygen concentrations in RSW 3P also increased rapidly to 12.0 mg/l during the filling of RSW 3P, while in RSW 3S they maintained a relatively steady and slow decline. The RSW 3P oxygen concentrations only remained elevated until approximately 10:35, when concentrations in the two tanks appear to converge briefly. After this period, oxygen concentrations in the two appear to diverge slightly. However, this difference is thought to be an offset in measurements by that particular logger in comparison with the others (#0056). Indeed, although there was no full in-tank calibration comparison test, a comparison of termination values at the end of the monitoring period (11:44 to 11:47 on 17th October shows that the logger in RSW 3P had an offset of minus 11.1% with respect to the logger in RSW 3S and minus 7.6% with respect to the logger in RSW 4P. [NB: The logger in RSW 4S had shut down prematurely, so no values were available for comparison]. This suggests that the small disparity between oxygen concentration in RSW 3P and the other tanks is likely to have been an anomaly due a small offset with respect to the calibration of the logger in that tank (#0056).

Cast #04 was a large cast (406.5 tonnes) which took 1 hour and 5 minutes to pump aboard (13:46 to 14:51). However, the catch was only pumped into RSW 4P and then 4S during approximately the last 15 minutes of those pumping operations. RSW 4P was filled with 50.9 tonnes of mackerel, displacing 53.02 m^3 of water, leaving a residual of 86.98 m^3 of chilled seawater. RSW 4S was filled with 19.2 tonnes of mackerel, displacing 20.00 m^3 of water, leaving a residual of 119.00 m^3 of chilled seawater. As all tanks were now in use, the exchange pump would now be operating at maximum capacity (600 m^3/hr), although divided between tanks this meant the effective exchange rate per tank was now reduced to 150 m^3/hr/tank. Therefore, the turnover/exchange rate in each tank was now reduced (see table A1).

The RINKO loggers in tanks RSW 4S and 4P were not installed until 16:20; i.e. 1:20 hours after the catch had been pumped into the tanks. So, there is no record of the change in these tanks due to the addition of the catch. However, prior to the catch being pumped aboard, water was transferred from the forward tanks into RSW 4S and 4P – which is thought to coincide with the small peak in temperature in RSW 3S and 3P. In addition, water temperature in RSW 3S and 3P began to increase once pumping operations began, with an accelerating rate of change over time. The installation of the RINKO loggers in RSW 4S and 4P coincided with the post-cast peak in temperature in RSW 3S and 3P. Furthermore, water temperature in RSW 4S had converged with RSW 3S and 3P, at minus 0.42°C, by approximately 16:50 (2 hours after pumping ceased). However, in RSW 4P, which contained a larger volume of mackerel, water temperature did not converge (at minus 1.49°C) with the other tanks until approximately 20:41, nearly six hours after pumping ceased. This delay is most likely due to the larger volume of catch reducing the cooling capacity of the residual water in that tank, despite the relatively higher exchange rate. However, it should also be noted that the RINKO logger in RSW 4P was also located at a shallow depth (~1.8m) than the other loggers, and so may have been exposed to higher temperatures due to heterogenous mixing in the tanks.

Dissolved oxygen concentrations in RSW 4S and 4P had already converged with the values (7.58 mg/l) in RSW 3S (and 4S, approximately) by the time the RINKO loggers were installed (at 16:20). This more rapid equilibration of dissolved oxygen between the RSW tanks is likely the result of rapid stripping of the available dissolved oxygen from the water by mackerel that already have a high oxygen debt, and thus oxygen demand. This process happens at a much quicker rate than the exchange of heat energy between the mass of fish and the surrounding water, due to water's high specific heat capacity.

Conclusions & Recommendations

This preliminary trial has been informative and suggests there are likely implications for large catches with respect to welfare and mortality in the RSW tanks. That is, temperature shock is likely to be reduced, which may prolong survival and exposure to stressors in the RSW tanks. Conversely, fatal hypoxic conditions are more likely to develop earlier, thus shortening the exposure to stressors inside the RSW tanks. Which of these two mechanisms is dominant is unclear and therefore further investigation is warranted.

For several reasons, the data in this trial was incomplete, so the exercise should be repeated to confirm these results, and better determine the interactions between the temperature and dissolved oxygen concentrations of linked tanks in a recirculation system. To this end, future observations should ensure:

i) All loggers are installed in the RSW tanks before the first tank is filled with catch.
ii) In-tank calibration comparisons should be performed with the loggers bundled together in the same RSW tank, with oxygen concentrations at close to 100% saturation, as well as under hypoxic conditions. This will help identify any post-calibration disparities between the loggers.