Sustainable catch and live-storage of bluefin tuna in Norway

Trials onboard «Sjarmør», Autumn 2022

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Summary

Despite the increasing presence of bluefin tuna in Norwegian waters and the initial interest shown by the industry to harvest BFT, low profitability in the fishery has led to that the quota assigned to the Norwegian fleet has not been fully harvested the last years. This low profitability is attributed to poor catch efficiency, lack of procedures and infrastructure to guarantee standards of quality, and poor marketing. Live-storage of BFT is regarded as a potential solution, at least partially, to mitigate the low profitability in the fishery.

In 2020 Norwegian authorities and the Institute of Marine Research (IMR) started a project to develop live-storage of Atlantic BFT. The aim of the project is to implement live-storage of BFT in Norway and develop the different procedures necessary from catch and monitoring of fish to transfer and storage in coastal cages. The project has four main focus areas: BFT identification, harvest, catch control, and fish welfare and quality. This is the third report of a series that sums up the developments and the results from the sea trials in 2022.

The sea trials were carried out at the end of September along the west coast of Norway between Bergen and Stad. The weather during the cruise was in general bad, which limited the effective sea trial period to three days. Despite the high number of observations of BFT during the trial period, the fish moved very fast, with no clear pattern, and in large aggregations, which made it very difficult to catch. Thus, the difficulties to catch the fish combined with the short trial period lead to no catches of tuna, which substantially limited the work that initially was to be carried out. However, some of the equipment tests carried out and the experience gained during the trial period are of interest for future work.

The operation of the sonar used for early identification of fish provided a clear view of the gear and would most likely also be able to identify BFT, which was satisfactory. The operation of the small mesh netting tested in the seine to avoid entangling fish and the installation of the stereo camera applied for catch control during the transfer process were also satisfactory from the operational point of view. Also, the surface ROV constructed with catch control and fish welfare monitoring purposes during the capture process showed also to work as planned, although we could not determine to what extent one would be able to identify BFT in the seine. As the catches in the trial period were absent, there were no tuna samples to evaluate fish welfare and quality at the level planned in the trials.

The present trials brought up some of the challenges in the BFT purse seine fishery that limit catches in the fishery and consequently the development for live-storage. Low profitability in the fishery together with the overlap with the mackerel fishery has lowered the participation of the fleet. This, added to the lack of infrastructure for fish delivery as well as the strict regulations and associated costs to enforce the right to fish, have contributed further to the low participation in the commercial fishery, which limit the possibility for R & D activities in the fishery.

Sammendrag

Til tross for den økende forekomsten av makrellstørje i norske farvann og den opprinnelige interessen fra næringen for å høste størje, har lav lønnsomhet i fiskeriet ført til at den norske kvoten ikke er fullt høstet de siste årene. Denne lave lønnsomheten tilskrives dårlig fangsteffektivitet, mangel på prosedyrer og infrastruktur som garanterer god kvalitet og dårlig markedsføring. Levendelagring av makrellstørje anses som en mulig løsning for å øke lønnsomheten i fiskeriet.

Norske myndigheter og Havforskningsinstituttet (HI) startet i 2020 et prosjekt for å utvikle levendelagring av makrellstørje. Målet med prosjektet er å innføre levendelagring av størje i Norge og utvikle de nødvendige prosedyrene fra fangst og overvåking av fisk til overføring og lagring i merder. Prosjektet har fire fokusområder: identifisering av størje, fangst, fangstkontroll, og fiskevelferd og kvalitet. Dette er den tredje rapporten i en serie som oppsummerer utviklingen og resultatene fra toktet i 2022.

Toktet ble gjennomført i slutten av september langs vestkysten av Norge mellom Bergen og Stad. Været under toktet var generelt dårlig, noe som begrenset den effektive forsøksperioden til tre dager. Det ble gjort hyppige observasjoner av størje i forsøksperioden, men fisken beveget seg veldig raskt, uten tydelig mønster og i store aggregasjoner, noe som gjorde fangsting svært vanskelig. Dette i kombinasjon med den korte forsøksperioden førte således til at det ikke ble fanget størje, noe som vesentlig begrenset arbeidet som i utgangspunktet skulle utføres. Noen av de utførte utstyrstestene og erfaringene i prøveperioden er imidlertid av interesse for videre arbeid.

Høyfrekvent sonaren brukt til tidlig identifisering av fisk ga en klar oversikt over redskapet og ville mest sannsynlig også kunne identifisere størje, noe som var positivt. Operasjonen av det småmaska panelet som ble testet i nota for å unngå hekting av fisk og installasjonen av stereokameraet brukt for fangstkontroll under overføringsprosessen var også driftsmessig tilfredsstillende. Overflate-ROVen konstruert for fangstkontroll og fiskevelferdsovervåking under fangstprosessen viste også å fungere som planlagt, selv om vi ikke kunne fastslå i hvilken grad man ville være i stand til å identifisere størje i nota. Ettersom fangstene i prøveperioden uteble, var det ingen fiskeprøver for å evaluere fiskevelferd og kvalitet slik som planlagt i forsøkene.

Disse forsøkene viste noen av utfordringene i ringnotfisket etter størje som fører til begrensing i fangstene og dermed utviklingen for levende lagring. Lav lønnsomhet i fiskeriet samt overlapp med makrellfisket har redusert deltakelsen til flåten. Dette, i tillegg til mangelen på infrastruktur for levering av fisk samt de strenge reguleringene og kostnadene for å håndheve retten til å fiske, har bidratt ytterligere til lav deltakelse i det kommersielle fisket, noe som begrenser muligheten for FoU-aktiviteter i fiskeriet.

Background

Atlantic bluefin tuna (*Thunnus thynnus*) (BFT) is the largest tuna species and is highly sought because it can reach high commercial market value (Collette et al., 2011). The Northeast Atlantic stock spawns in the Mediterranean during late spring and migrates to the Norwegian coast to feed on pelagic species (e.g. mackerel [*Scomber scombrus*]) during summer and fall. Norway had one of the world's largest BFT fishing fleets in the 1950s and -60s, with around 470 vessels that caught 15,000 tons in its peak year (Tangen, 1999). From the end of the 1960s and during the 1970s, the stock dramatically decreased due to overfishing (Cort & Abaunza, 2015). The stock collapsed in the mid-80s and Norway ceased fishing as observations of BFT became rare in Norwegian waters. However, a recovery plan initiated in 2006 by the International Commission for the Conservation of Atlantic Tunas (ICCAT) led to the recovery of the stock. Since 2012, tuna observations have become more frequent along the Norwegian coast (Nøttestad et al., 2020) and in 2014, the fishery was reopened with a small quota of 31 tons which has gradually increased to 315 tons in 2022.

Despite the increasing availability of the resource and the interest of the industry to harvest BFT, low profitability in the fishery has led to that the quota assigned to the Norwegian fleet has not been fully harvested the last years. This low profitability has been mainly attributed to poor catch efficiency, lack of procedures and infrastructure to guarantee standards of quality, and that Norwegian BFT is a new product in the international market with no established sales channels.

In order to mitigate the issues related to fish quality and market supply of Norwegian tuna, it is considered necessary to develop ways to properly store tuna for variable periods of time, which would help preserve its quality and provide sellers with flexibility as to when to supply the market. In 2020 Norwegian authorities and the Institute of Marine Research in Norway (IMR) started a project to develop live-storage of Atlantic BFT (Sistiaga et al., 2021). The aim of this project is to implement live-storage of BFT in Norway and develop the different procedures necessary from catch and monitoring of fish to transfer and storage in coastal cages.

The project has four main focus areas:

- Fish identification
- Fish capture
- Catch control
- Welfare and quality

One of the challenges in the Norwegian BFT fishery is the identification of species and numbers of fish in the pre-capture, during capture and post-capture phases of the fishery. The pre-capture and capture phases are especially important to avoid large catches (> 30 fish), and determining whether there is any catch in the seine at an early stage is key for increasing the success rate of storing BFT alive. The fleet used medium frequency (i.e. 75 kHz) omni sonars for detection and evaluation of the number of fish before shooting the net. However, the accuracy of the number of fish will vary depending on fish behavior and the possibility to monitor the fish for enough time before the start of the catch process. Previous experiences in the fishery have resulted in large catches, making the handling of the fish extremely complicated and preventing the realization of an efficient transfer to live-storage cages. Thus, additional information is required to better evaluate the number of fish in the catch at an early stage.

Early identification of BFT during the capture process is important because it also helps determining whether the protocol for live-storage of fish needs to be activated, i.e. deploying of the transport cage and joining of the seine and the cage by a transfer channel. One of the main problems during the capture process is that fish gets entangled in the large meshes of the seine. When fish gets entangled, the retrieval of the seine needs to be repeatedly stopped to disentangle the fish. The size of the fish requires the use of a crane to remove it from the seine net. Stopping the retrieving process of the net leads to higher entangling risk for the fish in the seine, which further complicates and delays the process. This has serious consequences for the welfare and quality of the fish as well as for the HSE conditions for the crew. A potential solution to this problem is the installation of a small-mesh netting panel in the part of the seine that is most exposed for entangling.

Good fish welfare is necessary during the capture process to ensure ethical handling of animals, high fish quality and survival of the fish stored in the cages, and it can be defined as: "capture and handling methods that minimize the physical damage to, and allostatic load on, any retained fish until after they are either slaughtered or released, and thus promote the likelihood for post-release survival and/or good product quality" (Breen et al, 2020a). Thus, by better understanding how and when during the capture process stressful/poor-welfare situations for the catch occur, it is possible to be able to improve the quality of the retained catch, which is one of the issues that is pendant for Norwegian BFT.

Monitoring the fish in the different phases of the capture process is necessary to evaluate welfare. In addition, cameras and acoustic monitoring devices are necessary to always control the numbers and whereabouts of the fish. This is especially relevant when the fish is transferred to the transport cage, which requires counting and measuring of every individual transferred.

The present report describes the status of the work conducted in the development of Live-storage of BFT in Norway in 2022. Specifically, the goals of the trials were to:

- Test a high frequency sonar for identification and counting of BFT individuals during pre-catch, catch and post-catch phases.
- Test a small-mesh panel to avoid entangling fish during the retrieval of the seine.
- Test a stereo camera equipment to count and monitor fish during transfer.
- Test a surface ROV for early identification of fish during capture and monitoring of fish welfare.
- Evaluate fish welfare and quality during/after catch and live-storage of fish.

Methods and Results

The sea trials were carried out between the 26th September – 4th October 2022. They were supposed to happen earlier in September but due to the problems of the fleet with the mackerel fishery, the cruise could not be carried out before. The Norwegian fleet fishing mackerel is not allowed to fish in British waters, and the vessel we had rented, like lost purse seiners fishing BFT, has a substantial mackerel quote they needed to harvest at the same time as the BFT fishery. Thus, the vessel had to pull off from our agreement and we had to find a new vessel, which caused a substantial delay. The vessel employed for the trials was "MV Sjarmør II" (1993), which is 35.30 m long, 9 m wide and has a gross tonnage of 582 tons. The trials were conducted along the west coast of Norway between Bergen and Stad (Fig. 1).

Fig. 1: The area in red shows the area covered during the fishing trials.

The cruise in general was impacted by bad weather, which limited the initial trial period of 10 days to 3 effective fishing days. The weather need to calm to fish BFT and specially to transfer BFT to a transport cage, and except for the first two days,the conditions were not good with winds of ca. 10 m/s and 3-4 m waves. During the period, BFT was abundant with high frequency of observations. Especially in the area between the island of Fedje and all the way north to Ålesund, the reports of observations from other vessels were very good.

Despite BFT being very abundant, the fish moved very fast and with no clear pattern, which made it very difficult to follow on the sonar. When fish was first observed on the surface, we tried to approach them, but the fish soon disappeared and appeared again many hundred meters away or simply disappeared. In these conditions, shooting the net was challenging and although we carried out several attempts, we were not successful capturing BFT. This was also the experience of the other commercial vessel fishing in the area, who reported up to 5-6 casts a day without catching any tuna.

Not being able to catch any BFT in the trial period limited substantially the work that initially was to be carried out. However, some of the equipment tests carried out and the experience gained during the trial period are of interest for future work.

Fish identification using acoustic methods

Multibeam high frequency sonars, like the Kongsberg M3 sonar (500 kHz), have a resolution high enough to discriminate single fish up to a range of 100 m. During a survey conducted onboard "MS Ytterstad" in 2021 (Peña et al., 2022), this sonar was successfully used to track free swimming BFT aggregations at a speed up to 4 knots. The transducer is relatively small (< 5 kg) and can be operated from a small boat.

Fig. 2: Pole for mounting M3 sonar. Whole pole with structure to attachment to the skiff and system to allow rest out of water when sailing and deployed when acoustic sampling (top panels). M3 transducer attached to the end of the pole in a platform with an hydraulic arm to allow tilting sonar head (bottom left). Detail of the attachment of the pole system to the skiff side (bottom right).

The M3 sonar was mounted in a pole on the side of one of the skiff available onboard Sjarmør. The aluminum pole was constructed for this purpose and attached to the port side of the small boat (Fig. 2). The pole had a hydraulic piston that allowed the change in the tilt of the sonar transducer. The sonar was operated using a car battery and a converter from 24 to 220 volts. A dedicated PC was running the M3 sonar software connected via ethernet cable.

The aim of these trials was to quantify the number of fish captured during and right after the purse seining operation. Due to the waves experienced in the trial period, the skiff with the arrangement to use the M3 could only be deployed in two settings. The target in both cases were small and highly mobile BFT aggregations, detected and monitored briefly with the sonar. In each setting, after the pursing of the seine was completed, the skiff was lowered from the vessel and approached the distal end of the net, away from the fishing vessel. Continuous registrations from the multibeam sonar were made adjusting the position of the skiff in order to cover the whole water volume inside the net. The transducer tilt was adjusted, but due to the close range between the small boat and the net, no significant difference in the acoustic sampling was observed. Data was stored locally and processed later in the same sonar software.

The operation of the M3 sonar onboard the skiff was satisfactory. Despite the high noise level and vibration caused by the outboard engine, it did not affect the sonar performance most of the time. In few occasions, the vibration level became too high and the sonar transducer lost communication with the PC. Due to the waves, the sea conditions were not ideal for the operation of the equipment. Nonetheless, the sonar head could be kept under water at all times.

The absence of catches in the trials limited the results. However, acoustic data from the M3 provided a clear view of the seine walls from the sides and from the bottom (Fig. 3). The water column inside the seine also was clearly observed, which is encouraging for future trials and indicates that the presence of tuna would have most likely been detected by the sonar.

A more silent and comfortable skiff will be recommended for future experiments. Few modifications can make the pole easier to maneuver, especially during the deployment. Sonar operation and data quality were satisfactory.

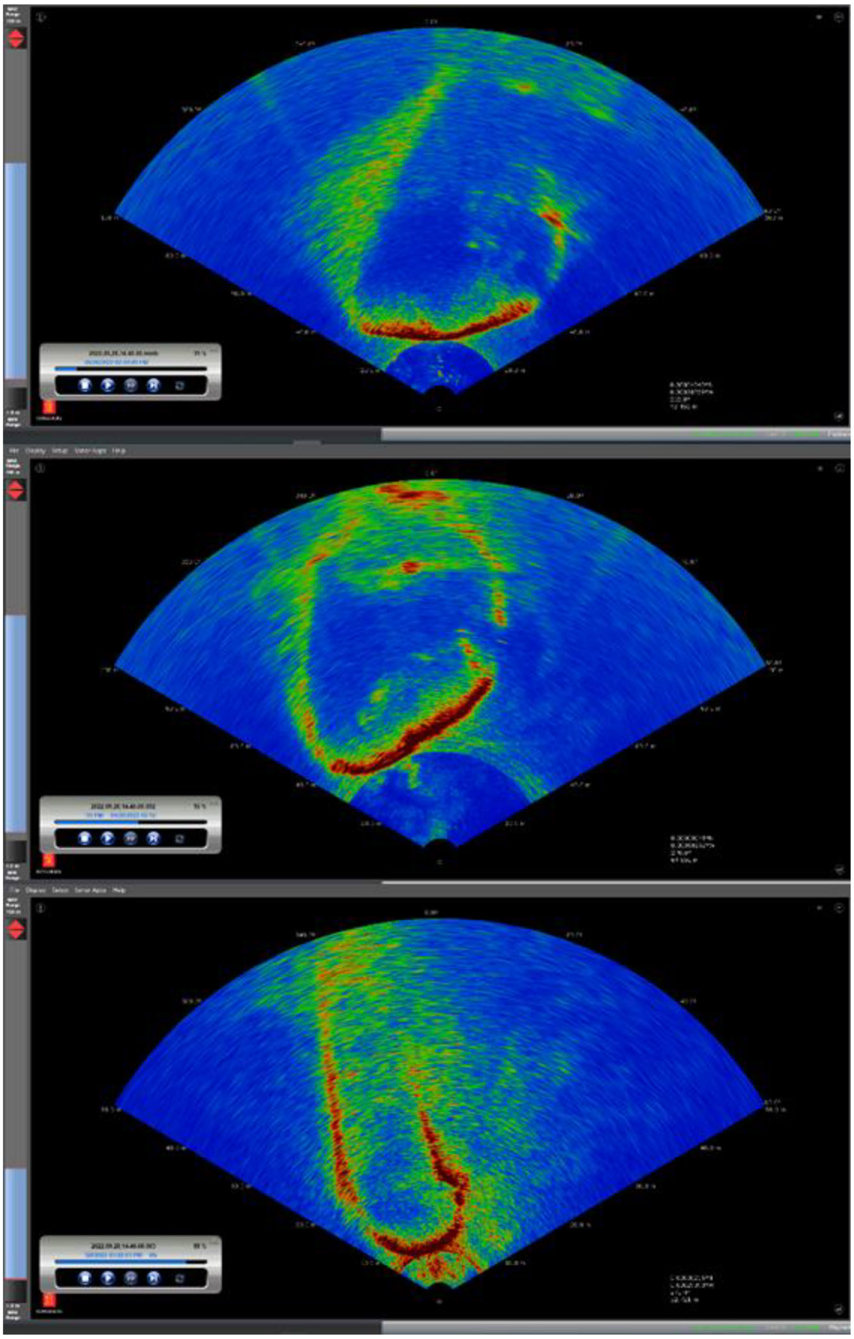

Fig. 3: Screen dumps from M3 sonar measured from a skiff on 28.09.22. The bottom red/brown echoes represent the purse seine net close to the transducer. In the opposite direction, at the top of each image is the vessel. From top to bottom the later stages during the retrieval process are shown. The top 2 images at a sonar range of 100 m, and the bottom image at 50 m range.

Small mesh panel in the seine

Earlier sea trials have shown that with the purse seines used by fishermen today, which have a mesh size of approximately 200 mm in the whole net, the risk for BFT entanglement is high, especially with large catches. BFT entanglement leads to substantial logistic problems for the crew due to the size of the fish and therefore, a panel with meshes of approximately 60 mm was inserted in an area where BFT has earlier been observed to get entangled (Fig. 4).

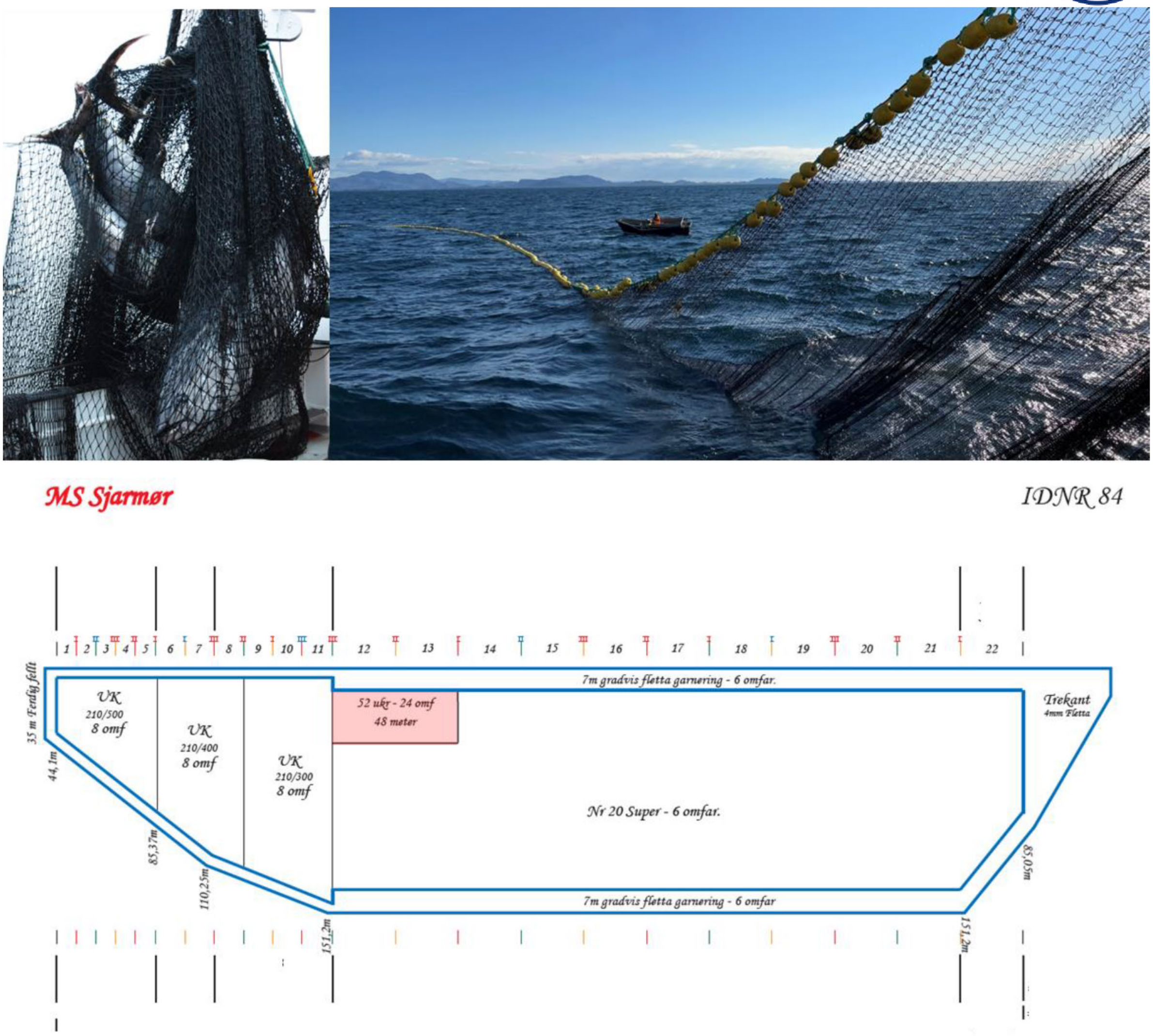

Fig. 4: Top panel left shows tuna entangled in the seine, top panel right shows the small mesh panel in the seine, and the lower panel shows the location of the small mesh panel (red area) in the seine.

The efficiency of the panel to avoid tuna entangling could not be tested because no BFT was caught during the trials. However, the trials showed that there were no operational problems handling a purse seine with such a panel inserted and it is anticipated that the measure will, at least to a certain level, mitigate the issue.

Stereo camera system

One of the goals of the trials was to test a stereo camera equipment to count and monitor fish during transfer. Earlier tests carried out before the summer at the harbor in Bergen showed that the system would be able to register tuna passing through the channel if the fish would not pass closer than 2 m from the camera. To avoid the limitations of the field of view of the stereo camera system, two systems were rigged and were planned to be set on both sides of the channel and ca. 2 m below the surface. The camera systems were fitted to steel frames that could be attached to the netting panels in the channel (Fig. 5).

Each customized stereo camera system comprised of two Gigabit Ethernet cameras, with a 1720 × 1080 pixel resolution and framerate of 35 fps. The cameras were mounted in an underwater housing, with a baseline of 85 cm and inward convergence of 5°. Camera synchronization was achieved using the IEEE 1588 Precision Time Protocol (PTP) [26]. The system is rated for a depth of 40 m and has an umbilical cable that supplies power over ethernet to the cameras and transfers images to a logging computer, which encodes left and right videos using GPU encoding. The stereoscopic system was previously calibrated using a checkerboard pattern.

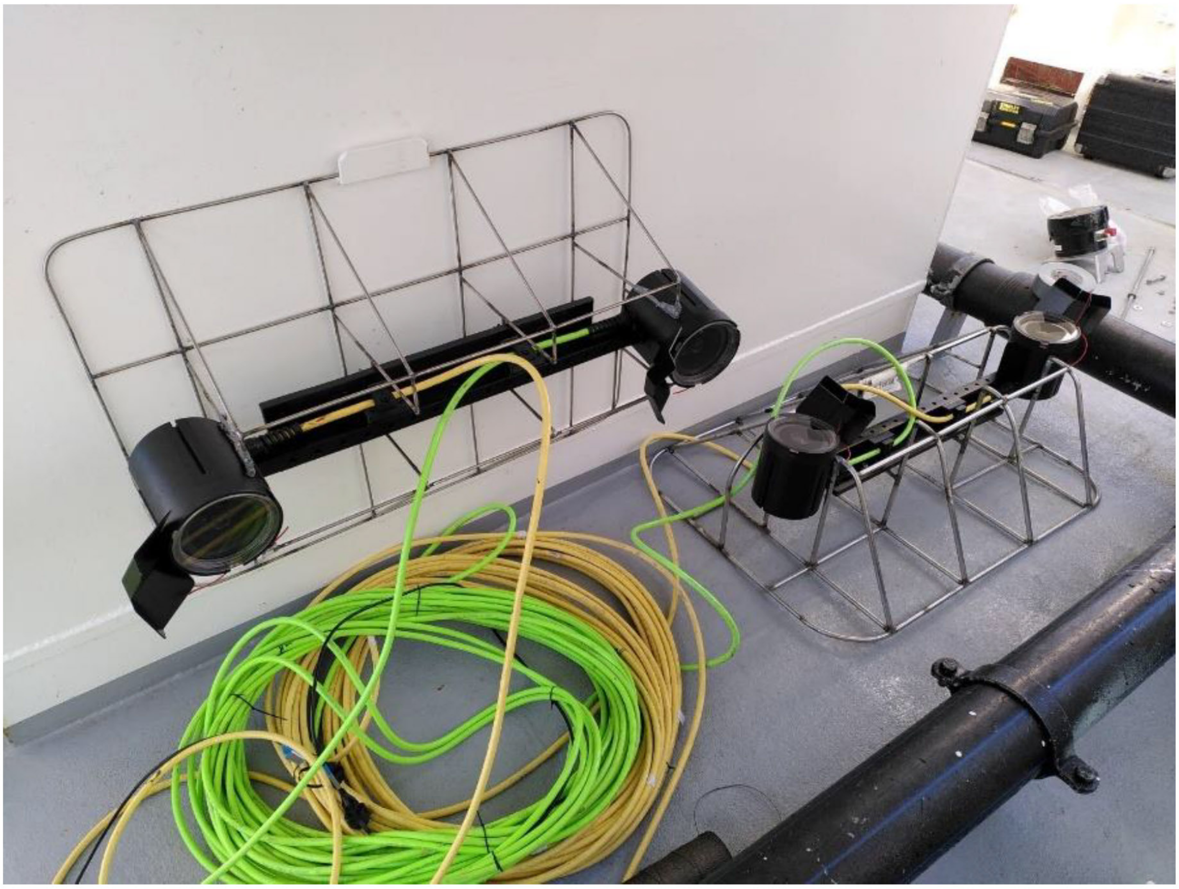

Fig. 5: Stereo camera systems rigged to be set on the side panels of the channel during BFT transfer.

Welfare monitoring - Behavioural observations

Based upon earlier experiences and the need to observe BFT in the seine, the development of a camera system that enable the real-time observation of catches in the purse seine was prioritised. This would allow the size of the catch to be estimated, as well as monitor its behaviour, to inform decisions on whether the catch should be transferred to the cage.

This real-time surface ROV consisted of three key components: 1) a deployment platform; 2) an underwater camera; and 3) communications system for transferring the images to the fishing vessel (Fig. 6).

1) <u>Deployment platform</u> - used the USafe motorised buoy system, that could be remotely controlled from up to 500 m. This was tested prior to and during the research cruise and

proved to be reliable and easy to operate. It was relatively easy to deploy from the fishing vessel and was easily recovered using one of the small boats.

2) Underwater Camera – development started with a modified GoPro Hero 9 camera, using its inbuilt WiFi to transmit the video signals via the wireless mesh network (see below) to the fishing vessel. However, initial trials showed that the camera transmission was unstable and would shut down if the signal to the vessel was briefly interrupted (>10 seconds). Unfortunately restarting the camera required recovering the system and reinitiating on deck. As a solution, an alternative Raspberry Pie camera was designed and constructed. During trials both before and during the cruise, this camera proved to be far more stable than the GoPro, although the image quality was not as good. A major advantage was that, once set up inside the underwater housing, the RaspberryPie camera could be left without having to reopen the housing to start the camera. Modifications to camera position and angle were required during the cruise, and this will likely require further development in the future to optimize camera views of the catch.

3) Wireless Mesh Network - this consisted of two Teltonika routers (RUTX10 & 11), linked to form a network that effectively extended the transmission range of each individual router by relaying signals (See Appendix 1 for more details). This wireless mesh network could be extended to include more routers and cameras (& other instruments) working over an extended range. The setup was different for the two camera systems (Appendix 1). The only camera tested on the WMN during the cruise was the RaspberryPie camera, but this was shown to give reliable and relatively stable images. There was some loss of signal, but this was generally regained after a few seconds and could likely be improved with the addition of more mesh nodes (routers).

Fig. 6: “USafe” buoy and camera system for monitoring tuna in a purse sein in real-time. Left – the Wireless Mesh Network router inside a water-proof yellow housing, with aerial cable, mounted on type of the “USafe” motorised buoy; Right: the RaspberryPie camera, inside a waterproof housing, mounted beneath the buoy, with a GoPro Hero 7 mounted above. [Image source: Jostein Saltskår].

In addition to the system described above, several other camera monitoring systems were deployed during the trials including: an in-house real-time stereo-camera probe, (Breen et al, 2021) and various GoPro cameras for underwater observations in the purse seine and cage; a stereo camera system (University of València), for observation and measurement of fish during transfer from the purse seine to the cage; and the Noldus Observer XT system, with two CCTV cameras mounted on the vessel's wheelhouse, to observe activities on deck and at the surface in the purse seine. Collectively, these systems would have been used to monitor key behavioural and vitality metrics detailed in the 2021 report.

Welfare Monitoring – Physiology, Injury, Condition & Quality

It was planned to take blood and tissue samples from all tuna killed during this research cruise to determine their physiological status. Hematological metrics to be determined included blood glucose, blood lactate, hemoglobin, hematocrit, as well as plasma osmolarity, dissolved ion content, and plasma cortisol. To assess the condition of the fish, fork length (curved and straight) would be taken at the point of death which, with total and somatic weight estimates, would be used to determine relative condition indices. Stomach fullness, contents and digestion level would also be recorded, along with visceral fat levels. In addition, it was planned to photograph and describe external injuries to the body and fins of each tuna.

Muscle samples would be taken from the core (posterior to the pectoral fin) and the tail (anterior to the peduncle) to determine quality metrics (i.e. colour, protein and fat content and enzyme activity) and monitoring for the occurrence of burnt tuna syndrome (BTS). Also, core muscle temperature and pH would be monitored at the time of death and then later at the point of delivery. Rigor mortis would be assessed at each muscle sampling point, and through degree of shrinkage in fork length (curved and straight), at the time of death and then later at the point of delivery.

To enable tuna to be removed from captivity and slaughtered with minimal stress to the animals and hazard to the crew, we planned to test a commercially available electrical stunning system. The system is suitable for deployment in small boats, because it is water-proofed and can be operated from a 24 volt battery supply. However, the battery pack is heavy (~50 kg) and the pole with the stunning electrodes is ~3.5 m long.

The system was tested in seawater several times, both prior to the trials in Bergen and aboard Sjarmør during the cruise. These tests demonstrated that the system was functioning correctly and safely (as determined by in-system testing) and was relatively simple to set-up.

To facilitate the trial stunning of tuna, a channel was constructed that would allow individual fish to be herded out of the transfer cage and into a shallow, closed end (Fig. 7). [Note - When not being used to stun fish, the stunning end can be removed, and the channel used to transfer fish to another cage]. The plan was for fish in the transfer cage to be herded to the channel end, by partially heaving in the far end of the cage using the triplex on the fishing vessel. Then individual fish would be guided into the entrance to the channel. Here the fish could be isolated, by closing the entrance of the channel at the cage, as well as at the entrance to the stunning section. Researchers would then have unrestricted access to and control of the fish while applying the stunning electrical field. When stunned, the fish would sink to the bottom of the stunning section, where the researchers would still be able to access it and attach lifting strops for transfer to the fishing vessel using a crane.

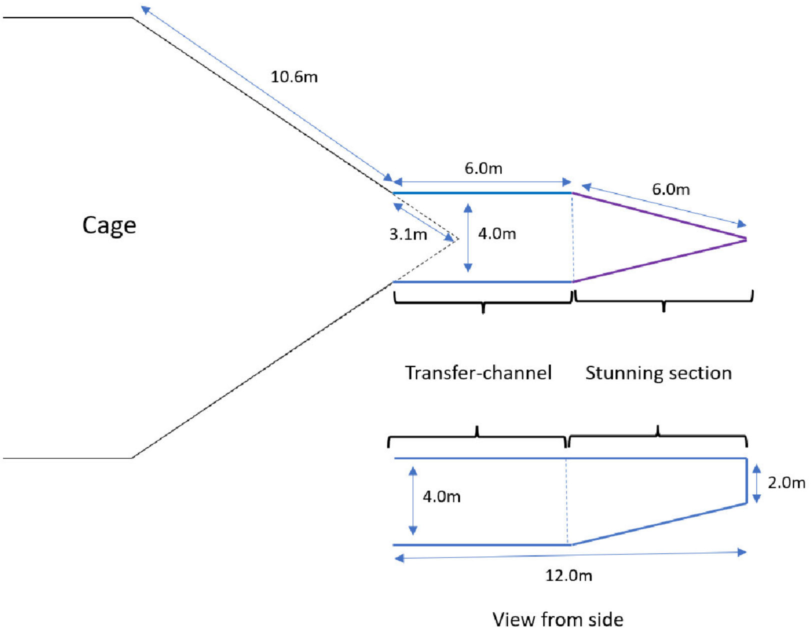

Fig. 7: Schematic overview of the transfer and stunning channel attached to the main transfer cage; insert below right: a side view of the transfer and stunning channel, with approximate dimensions. Further details on the transport cage can be found in Appendix 1.

Discussion

The sea trials in 2022 were impacted by bad weather and challenging fishing conditions in general, which led to the consequence of not being able to capture any BFT during the trial period. The same issues led to poor catches by the few commercial vessels in the fishing area at the same time. Further, this was the same outcome as in the trials from 2021, which proves that despite the abundance of fish on the fishing grounds, catching BFT is challenging. In other areas like in the Mediterranean for example, tuna behaves more calmly as it is in “spawning modus”, and the fishery is carried out in a different way with a different level of cooperation between the vessels and modus operandi than in Norway. Tuna in Norway, especially towards the end of the season in October, behaves more erratically with fast unforeseen movement patterns that makes it difficult to catch.

The first and most important premise for being able to live store BFT is actually catching it. Until the fleet can catch BFT regularly and with a high level of control over the fish during the harvest process, the chances of live-storage succeeding will be rather low. Therefore, we suggest that the trials in the coming years focus on the harvesting part of the process.

One of the main challenges in the fishery at the moment is the low prioritization of the BFT fishery by the fishermen mainly due to low profitability, which lowers the accessibility and possibilities for R & D that require cooperation with commercial activities. For different reasons (e.g. handling of the fish), Norwegian BFT has not acquired the expected prices in the market since the fishery was reopened in 2014. In addition, the BFT fishery is strictly regulated and requires the presence of an observer onboard, which adds substantially to the costs of participating in the fishery for the vessel. Further, most of the purse seiners harvesting BFT have a mackerel quota, which for many of these vessels is their main source of income. Because these vessels can no longer operate in British waters, they need to fish their mackerel in Norwegian waters and during the BFT fishing season before the mackerel migrates west. As long as there is no political solution and these vessels can not fish within British EEZ, this problem will perdure, as the fleet will continue prioritizing mackerel instead of BFT.

Although finding BFT was not a problem during the trials, the low participation of the fleet could in the future add to the risk of not being able to find fish. Specially earlier in the season, where the aggregations of BFT are smaller and the conditions (e.g. weather, water temperature, etc.) most likely more suitable for live-storage of fish, lower number of active vessels in the fishery can add to the already challenging process of harvesting BFT.

The uncertainty in the fishery today is reflected on the fact that only three out of the eight purse seiners with BFT quota have enforced their right to fish and that overall, only one third of the quota allocated to Norway in 2022 was harvested. The problem of low willingness to invest in the fishery by the fleet, is further accentuated by the lack of infrastructure and routines to deliver BFT. This contributes to the low prices achieved in the market.

Some of the equipment tested prior to and during the fishing trials presented here (e.g. stereo camera systems, stunning equipment, surface ROV) showed promising results. However, it is necessary to test them during a real fishing operation with fish to further develop them towards a potential future commercial use. This again stresses the need to focus on the harvesting element of the live-storage process because until this part is in place, the rest of the elements of the process are difficult to develop e.g. tuna monitoring equipment. The pole and line fishery for BFT has developed substantially in the last years and the catch efficiency in the fishery has increased, especially in 2022. Part of the development necessary regarding fish quality and welfare can be carried out in this fishery rather than the purse seine fishery, meaning that some of the fields relevant for the live-storage process can be developed using other fishing gears. This shows the importance of good communication and collaboration between the different fleets harvesting BFT in Norway to move the fishery forward and achieve the established goals e.g. live-storage of fish.

Acknowledgements

We would like to thank the Directorate of Fisheries for their help in acquiring the permits necessary to carry out the experiments and the assistance of Hermann Pettersen during the trials. We would also like to thank the Institute of Marine Research as well as the Norwegian Seafood Research Fund for their financial support.

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Appendix 1

Schematic drawing of the transport cage built for live-storage trials.