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Test of ROV-based harvesting methods for sea urchins and scallops

Part Two: Report on Scallop (stort kamskjell) collection trials

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Report

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Summary (English):

A series of trials were conducted to test the efficacy of the SeabedHarvester ROV for collecting scallops. The ROV had a specifically designed collector installed for the scallop trials. The trials were undertaken in December 2011 (Frøya), April 2012 (Frøya) and September 2012 (Helgeland).

Catch rates improved significantly over the course of the trials as a result of the modifications made to the collector between trials, and the increasing confidence of the ROV pilots. The maximum catch rate recorded in Trial 3 was 46.9 kg/hr. This is approximately half the catch rates required to make the use of the ROV economically viable according to industry estimates. The authors believe the catch rates recorded in the trials are very conservative compared to what the optimal catch rates would be. Further trials would be required to define the maximum catch rates the ROV is capable of collecting. Although the catch rate needs to be improved the ROV does offer a number of advantages over traditional dive operations for scallops. These include:

- The ROV only requires a single operator (compared to 4 divers) reducing the logistics of organizing a dive crew
- There are none of the health and safety issues/restrictions associated with diving
- The ROV is not depth or time restricted as are divers and can fish scallops at depths from 1-100m depth for as long as it takes to fill the catch tray

Summary (English) continuation:

The ROV is as environmentally friendly as dive operations and there were no obvious differences in shell quality in scallops collected by ROV compared to scallops that were handpicked by divers.

The authors made the following recommendations at the conclusion of the trials:

- The trials have shown that it is possible to catch scallops using the ROV
- The modifications made to the scallop collecting system throughout the trials have made significant improvements in catch efficiency. However, further refinement is needed in order to increase catching efficacy
- In order to reach the target catch of 800-1000 kg/day the catch rates recorded by the ROV would need to be doubled
- Further testing is recommended to familiarize a pilot with the use of the ROV and to establish whether it is economically viable to utilize an ROV for scallop collection.

Sammendrag: (Norwegian)

En serie med forsøk ble gjennomført for å teste fangsteffektiviteten til en spesialutviklet miniubåt for fangst av stort kamskjell. Det ble gjennomført tre fangstforsøk på Frøya og Helgeland (desember 2011, april 2012 og september 2012) med miniubåten SeabedHarvester (ROV).

Fangsteffektiviteten økte signifikant over tid, som et resultat av økt erfaring hos ROV–piloten og modifiseringer av utstyret mellom hvert forsøk. Maksimal fangsteffektivitet i det siste forsøket var på 46,9 kg/timen. For å få en økonomisk lønnsom innhøsting av store kamskjell ved bruk av ROV må fangstene dobles.

Ut fra erfaringen vi har fra disse forsøkene mener vi at ROV har et stort potensial for fangst av stort kamskjell. Fangst ved bruk av ROV er miljøvennlig og det er en bærekraftig fangstmetode som ikke skader dyrene eller miljøet. Nedenfor er det listet opp fordeler ved bruk av ROV sammenliknet med dykking:

- Ved bruk av ROV trengs bare en operatør (sammenliknet med 4 dykkere), noe som gir redusert logistikkkostnader
- Utfordringer knyttet til sikkerhet og helse er minimal sammenliknet med dykking
- Bruk av ROV ved fangst gir ingen dybdebegrensninger under fangst, og den kan operere fra 1 til 100 m

På bakgrunn av de innledende forsøkene er våre konklusjoner og anbefalinger følgende:

- Forsøket har vist at det er mulig å fange stort kamskjell ved bruk av ROV
- Tilpasningene og modifiseringene gjort under forsøket førte til forbedring i fangsteffektivitet, men flere tilpasninger er nødvendig for å forbedre fangsten
- For og nå et mål på 800-1000 kg pr dag må fangsteffektivitetene dobles i forhold til dagens nivå
- Det er behov for større feltforsøk hvor man benytter en erfaren ROV-pilot for å evaluere økonomisk lønnsomhet ved bruk av ROV i fangst av stort kamskjell.

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1 Introduction

1.1 General introduction

Since 2000, the reported catch of giant scallops (*Pecten maximus*) in Norway has been in the range 500-900 tonnes per annum. In 2009, 748 tonnes were harvested in total. That was 17 % less than in 2008, and less than the previous three years. More than 80 % of landings take place on the islands of Hitra, Frøya and Froan, where the catch has declined over the past two years. Meanwhile, catches in Nord-Trøndelag have increased over the same period. The reduction in the total catch was due to a fall in market demand (information from IMR website). In Norway, giant scallops are exclusively harvested by divers, who operate in diving teams from registered fishing vessels. The divers are normally breathing Nitrox gas, mixed and supplied from the surface. Unfortunately the inherent dangers in this type of work mean that there have been a number of fatalities in the scallop diving industry in the past few decades. The most common alternative method of fishing scallops is the use of a scallop dredge and this is used in a number of countries around the world. However, this is a very destructive technique for the local benthic environment and it is prohibited in Norway. An alternative technique, that would have a very limited impact on the benthic environment and would alleviate the inherent risk of diving for scallops, is the use of underwater remote operated vehicles (ROV's). The Norwegian company 7S-Technology AS has been investigating the use of a purpose built ROV for harvesting a number of marine species and this report summarizes the initial trials conducted on the collection of the giant scallop (*Pecten maximus*).

1.2 Aim of project

The project aims are as follows:

- Determine whether it is possible to collect scallops using the ROV
- Make an estimate of the catch efficiency of the ROV
- Compare damage or loss of quality of scallops caught in the ROV compared with those caught by divers
- Describe any environmental challenges or limitations for harvesting scallops with the ROV
- Comment on whether using the ROV is a realistic alternative to the current collection technique (use of divers).

Figure 1 The giant scallop (stort kamskjell), Pecten maximus.

2 Trial 1 and 2: Frøya (December 2011 and April 2012)

2.1 Methods and results

2.1.1 Vessel description

The vessel used in the Trials 1 and 2 was a 13m catamaran dive boat (Sverre Junior) (Figure 2). The vessel has a crane in the centre of the rear deck which can be used for launching and retrieval of the ROV. The crane was also used to set and retrieve the single anchor which was used to hold the boat in position. The boat is owned and operated by Frøya Dykkeservice AS. The company owns and operates a Sub Fighter 7500 ROV and the skipper/crewman/ROV driver (Rune Myrseth) has extensive experience using a Sub Fighter 7500 ROV for aquaculture inspections and fish cage cleaning. Therefore, he is very familiar with the handling of the ROV from this vessel.

Figure 2 The Sverre Junior used in Trials 1 and 2 at Frøya.

2.1.2 ROV description

The SeabedHarvester ROV (Figure 3) used throughout this study is a specifically designed ROV for collecting benthic species such as sea urchins and scallops. It is a modified Sub-fighter 7500 ROV (165cm long x 96cm wide x 110cm high, 460kg, running off single phase 230 VAC power source) with a control unit (including monitor: 96cm long x 53cm wide x 63cm high), a remote control unit and a transformer unit. The ROV has been modified with the addition of a suction nozzle that protrudes from the front and is the point of collection. This nozzle is then connected to a storage tray which slots into the main body of the ROV (capacity approximately 100kg). A thruster creates the suction required to suck scallops from the catching system mounted on the front of the nozzle, into the storage tray. Once the tray is full the ROV must be retrieved into the support boat for emptying, before fishing can continue. The nozzle is a simple rounded polyethylene tube (200mm diameter) which is connected to a flexible hose in the aft and to a purpose built aluminum body in front. The aluminum body is shaped to accommodate scallops with a specially designed catching system (rake). This consisted of a rounded rake extending from the front of the suction tube used to scoop the scallops (Figure 4). Once the scallops were sitting on the rake a hydraulic arm lifted the rake to enable the scallop to slide back towards the tube where it would be sucked into the storage tray.

Figure 3 Are Hofstad (CEO of 7S-Technology AS) preparing the SeabedHarvesterROV prior to the trials at Frøya.

Figure 4 The modified extension on the ROV suction tube designed for collection of scallops. The steel rake is designed to pick up the scallop and tip upwards (as shown by the orange arrow) to bring the scallop into the range of the suction from the tube.

2.1.3 Trial 1: December 2011

The first scallop fishing trial was conducted between December 12th - 13th (2011). The site selected for the trial was an area approximately 0.5km offshore from the Seashell AS processing plant on Frøya.

The site consisted of a shallow (6-7m) sandy area with flat bottom which is used as a live storage area by Seashell AS. The scallops are fished from wild populations and brought to the site where they are temporarily stored on the seafloor prior to being collected by divers, landed and sent to market.

On the first day of the trial (12th December), Are Hofstad and Rune Myrseth were present for the set up and preparation of the SeabedHarvester ROV. Once the ROV set up was completed two test dives were made to ensure the equipment was functioning correctly. During the first two trial dives some scallops were collected but the ROV immediately ran into problems with the “scallop rake” mounted on the front of the suction tube becoming stuck in the sand as it was collecting the scallops, causing the whole ROV to tilt forward and the rake to dig into the sand. It was also noted that there were problems sucking some of the scallops into the ROV once they caught them on the rake because they ended up too far away from the tube (Figure 5). At this point the test was concluded for the day.

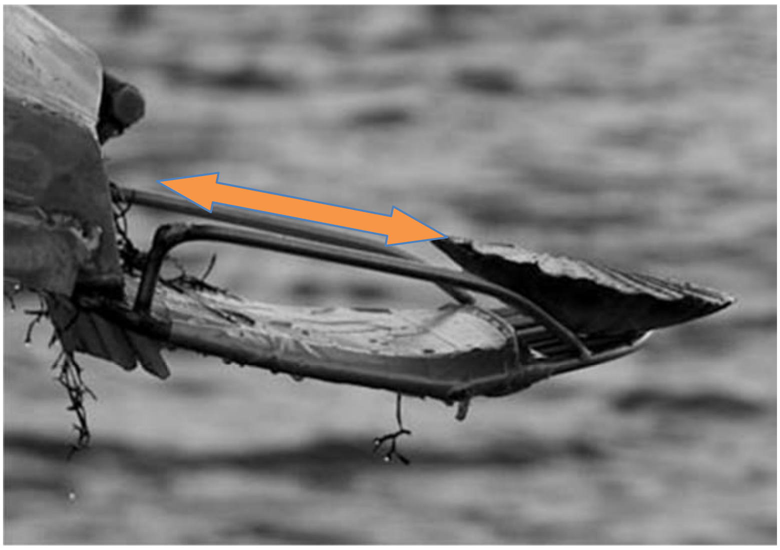

Figure 5 Scallop not getting sucked in from the tip of the rake (the distance shown by the arrow is too large). On this picture the rake is modified. Originally the slits extended all the way from the tube to the end where the scallop is in the picture

On the second day of the trial (13th December 2012), Rune (SeaShell AS) and Tor Evensen (Nofima) were present to conduct a further series of test on the ROV. The first dive was done without any modification to the equipment and was conducted in the same area as the previous day before. The same issues that had caused problems the previous day occurred (not being able to suck in all animals caught on the tip of the rake and the ROV getting stuck in the sand and tilting forward). The ROV was hoisted onto the deck and minor modification to the rake were made (the slits were covered to improve the suction on the rake surface, Figure 6) which improved the suction (this was not measured empirically). However with the slits covered the tendency for the rake to get stuck in the sand increased. In an attempt to use more forward throttle to get it loose (instead of backing out) the welding on the connection for the hydraulic arm broke off and fishing was aborted until a repair could be completed. There was no welder or welding equipment available on site so it was fixed temporarily with a steel bar and hose clamps. The rake was also further modified with a split in half length of 10” flexible tube and duct tape (Figure 7). This was done to further improve suction before the next test.

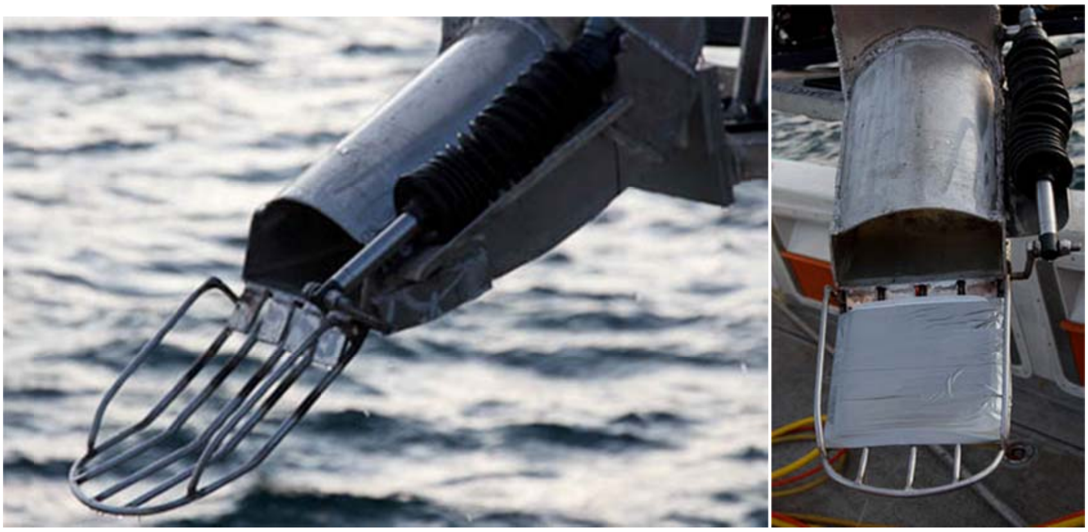

Figure 6 The rake before and after the first modification.

Figure 7 Broken welding and repair (second modification in Trial 1).

Following these modifications another test was conducted. In this test the ROV was driven very carefully (backing it out of stuck-in-the-sand situations instead of using forward thrust). This approach worked initially but the ROV once again got stuck and broke (due to it having to much speed when going into catch a scallop). After this second setback the vessel returned to shore.

It was obvious that the issue of getting stuck in the sand had to be resolved prior to continuing fishing. A number of possible solutions were discussed and it was agreed that modifications to the ROV were required prior to any further fishing trials.

2.1.4 Trial 2: April 2012

The modifications to the collection system (rake) recommended at the conclusion of Trial 1 were made to the ROV. These consisted of adding a skid onto the bottom of the collection system so that it could not dig into the sand (Figure 8). After this modification was complete the ROV was returned to Frøya for the second fishing trial (NB: the ROV was used to fish sea urchins in Båtsfjord inbetween Trials 1 and 2). On 26th April the ROV was reloaded on the Sverre Junior which returned to the same fishing spot described in Trial 1. There was an immediate improvement in catch rates (Table 1 and Figure 9) with the skid stopping the tendency of the ROV to nosedive.

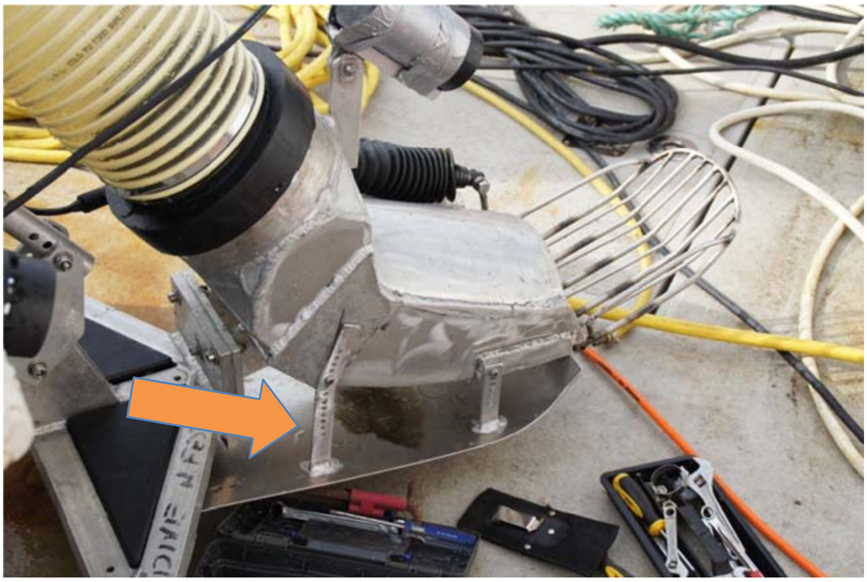

Figure 8 The modified collection system (rake) with a skid attached underneath (shown by orange arrow) to avoid the ROV nose diving into the sand.

Unfortunately on the 3rd dive the rake on the front of the ROV was once again bent out of alignment and required reinforcing. This was a relaitively simple excercise and was completed at a local workshop and the ROV was returned to the water later the same day. On the first dive back in the water the ROV went 'dead' in the water and it was hand hauled back alongside and lifted aboard. The cause was an electrical malfunction and later inspections showed this to be a blown fuse (resulting in a small electrical fire) in the main electronics cylinder of the ROV. The cylinder was removed and sent to Sperre AS (the company that built the ROV) for repair the same day and it was not possible to continue with the fishing trial until the repair was effected.

Following the electrical issue on the 26th it was decided to approach FHF and request an extension of the experimental period to undertake a 2 day fishing trial (organized and run by Seashell AS) once the electronic cylinder had been repaired. This request was approved by FHF.

Table 1 Scallop catch rates on 26th April prior to mechanical failure

	Dive duration	Scallop catch (number)	Catch/hr
Dive 1	10 minutes	10	60
Dive 2	29 minutes	40	80
Dive 3	29 minutes	20 (bent arm during dive)	40
Average catch/hr on 26th April			60

Figure 9 Scallops in the storage tray on 26th April.

During the testing on 26th April a number of scallops collected by ROV were photographed as they were removed from the catch tray (Figure 9) and later in the day a number of scallops that had been collected by divers and were being held in the live storage facilities at Seashell AS were photographed to compare the shell damage in each (Figure 9, 10 and 11).

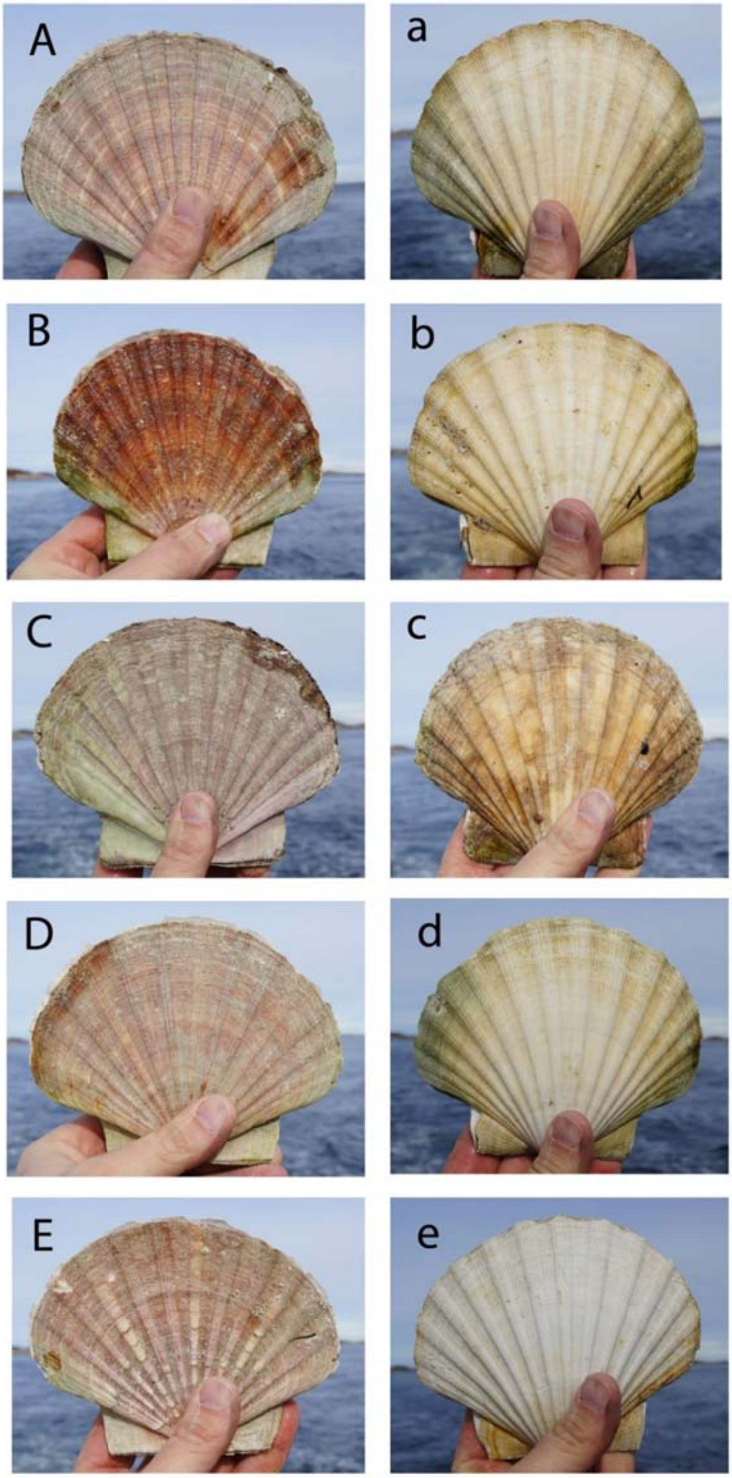

Figure 10   The shell condition of five scallops collected using the ROV (Upper case letters show the bottom side and lower case the top side of the shell).

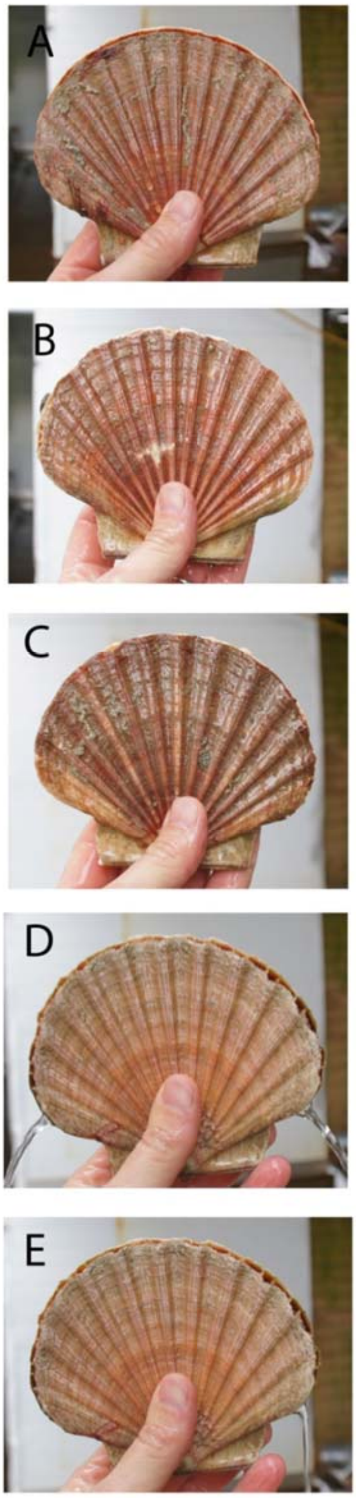

Figure 11 The shell condition of five scallops hand collected by divers (Upper case letters show the bottom side and lower case the top side of the shell).

Figure 12 A close up comparison of the condition of the bottom shell of a scallop fished using the ROV (top) compared to hand collected by divers (bottom).

During the collection trials 1 and 2 the bycatch made up approximately 20% of the total catch. Figure 13 shows the typical bycatch from this area which primarily consisted of echinoderms such as sea stars, sea urchins and sea hairs, algae, soft coral and empty razor shells. It is likely that the bycatch will change significantly depending on the area where fishing occurs. Because the Trials 1 and 2 were conducted in a shallow area, close to the seashell facility where scallops are often dropped and stored the fauna and flora at this site is probably not atypical of the areas that scallops are normally collected in (10-30m on sandy bottom). The bycatch was not monitored in Trial 3.

Figure 13 The typical bycatch at the Frøya collection site consisting of echinoderms (sea urchins sea stars and sea hares), coralline algae, algae and empty razor shell.

3 Trial 3: Helgeland (September 2012)

3.1 Methods and results

The repair/modification of the ROV after Trial 2 at Frøya took longer than expected. Subsequently, SeaShell and the ROV pilot used in Trials 1 and 2 were unable to conduct the last test due to prior obligations. In order to be able to complete the tests with the new improved nozzle, it was therefore decided to move to Sandnessjøen where 7S-Technology organised the use of a diving vessel for a short test, using an experienced ROV pilot.

The vessel used in Trial 3 was a 50ft diving vessel "Skjærgården 1" (Figure 14), owned and operated by "JR Dykk" in Sandnessjøen. This vessel has a Palfinger crane located in the fore port side of the boat. The operation of the ROV and anchoring was conducted similarly to the trials at Frøya. This company has extensive knowledge regarding diving operations in the area and has had many years of experience in scallop diving. The ROV was operated by a professional ROV operator, Marius Nilsen, who normally works with larger ROV systems on offshore vessels.

Trial 3 was performed in the area Måsvær in Herøy County on the 3rd September 2012. The weather conditions were very good and the sea was calm. Unfortunately the boat and ROV driver were only available to conduct the trial for one day due to other commitments for both the diving vessel and the ROV operator.

Prior to beginning the trial the skid under the nozzle of the collection system was adjusted manually to allow the ROV to conduct continuous harvesting. As the vessel is a monohull, and the ROV weighs about 500kg, the vessel listed heavily when the ROV was deployed over the side of the vessel. This resulted in the generator stopping due to an obstruction in the diesel supply. This required an *insitu* repair of the generator. Four dives were then undertaken. On the fourth dive the electronic actuator that lifts the rake was damaged, indicating that the angle between the skid and the seabed was too large and the rake was digging into the sand. However, when the rake was kept higher in the sand during the trial it was possible to move the ROV forward continuously whilst harvesting scallops and if this technique is perfected (i.e. the skid is tuned to the correct angle and the operator gets more experience) it will substantially improve the catch rates of scallops by the ROV.

Figure 14 The 'Skjærgården 1' used in Trials 3 at Helgeland.

Table 2 Scallop catch rates during Trial 3 at Helgeland (NB: weights are calculated using an average weight of 350g for each scallops)

	Dive duration	**Scallop catch (number)**	**Catch/hr (number)**	**Estimated Catch/hr (kg)**
Dive 1				
Dive 1a	10:00 minutes/secs	11	66	23.1
Dive 1b	08:05 minutes/secs	15	112	39.2
Average dive 1			*89*	*31.2*
Dive 2				
Dive 2a	12:35 minutes/secs	30	144	50.4
Dive 2b	21:28 minutes/secs	44	123	43.1
Average Dive 2			*134*	*46.9*

Figure 15 *Scallops in the storage tray on 26th April. There was very little bycatch present in the catch.*

Figure 16 *The size range of scallops collected at Helgeland; the largest scallop (top) = 17 cm/535g and the smallest scallop (bottom) = 10 cm/128g. The average size of the scallops was 375g.*

4 Discussion of results (Trials 1 - 3)

4.1 Suitability of boat design

4.1.1 Frøya trials

The boat used in Frøya (*Sverre Junior*) to operate the ROV was a purpose built catamaran for operating a similar sized ROV and was very efficient. This highlighted the importance of having a suitable boat to operate the ROV. During the urchin collection trials made in January 2012 the larger boat that used was extremely difficult to anchor and maneuver and the higher sides of the vessel made launching and retrieval of the ROV much more difficult.

The vessel used in the scallop trial 1 and 2 had a similar anchor system (a single anchor lifted over the side of the vessel using the deck crane). However, being a catamaran it was very stable during this operation. In situations where there were strong wind and current a double anchor (front and back) operated by a winch would allow for easier and more secure and stationery anchoring. If the boat is held stationary, regardless of current and wind, this would also allow for optimal use of the ROV.

4.1.2 Helgeland trials

The boat used during the Helgeland trial was a 50ft monohull diving boat with a water jet system which made it very fast and possible to reach remote locations in a relatively short time. As in the previous trials the boat also used a manual anchoring system which is not recommendable for this type of operations as the location must be changed continuously. We also had to use an external power source as the boat was not equipped with sufficient power generation to operate the ROV. Although the speed of the boat was a great advantage the reduced deck area and also reduced stability compared to the catamaran were major disadvantages and should be considered when designing or choosing a boat for any future ROV operations. The results from this study indicate that for future operations, a catamaran with an automatic mooring system and a high operating speed would be optimal.

4.2 Catch rates using ROV

The catch rate recorded in Helgeland (average hourly catch = 134 scallops on Dive 2; estimated equivalent weight = 40.2kg) increased almost twofold compared to the catch rate in the initial trial in Frøya (average hourly catch = 60 scallops; estimated equivalent weight = 18.0kg) (See Tables 1 and 2).

These catch rates should be considered as being conservative given that, although the pilots used in both trials were very experienced ROV pilots, it was the first time either had fished scallops with the modified ROV. As the pilot became more comfortable with the technique for fishing there is no doubt that the efficiency of this fishing technique would increase significantly (as was the case between Dive 1 and 2 at Helgeland).

The modifications made to the ROV during and between trials also dramatically increased the efficiency of collection. The addition of the skid to prevent the front rake digging into the sand was the most important modification. It may be possible to increase the efficiency further with more slight alterations to the suction head and the rake arrangement and 7S-Technology AS will make further modifications accordingly.

Catch rates improved significantly over the course of the trials as a result of the modifications and the increasing confidence of the ROV pilots. Therefore, the catch rates recorded in the trials are likely very conservative and should not be considered the maximum catch rates the ROV is capable of collecting.

The reliability of the collecting system was an issue during the trials with breakages in the unit itself as well as an unrelated electrical fault in the ROV which resulted in significant delays in the project and limited the time the ROV could spend in the water fishing. 7S-Technology AS are aware that the reliability of the equipment is extremely important aspect of commercial fishing. They are working to improve the reliability of the both the collection unit and the ROV. It should be noted here that the ROV was exceptionally reliable during the sea urchin trials run between scallop trials 2 and 3.

Equipment failure is not an uncommon issue with fishing and diving operations and one very positive aspect of the ROV is that equipment failure does not endanger any lives as is the case with diving operations.

4.3 Comparison of ROV catch rates with other catch methods

The average catches reported by Seashell AS in Frøya are 200-250kg per diver per day. A normal dive team consists of 1 boat driver and 4 divers operating from a single boat. The average landings would be in the order of 800-100kg/day/boat (Helge Myrseth, *Pers com.*). Seashell AS estimates that a similar catch rates (per boat) would be necessary to make the ROV economically viable as a fishing tool. The maximum catch rates recorded during the three scallop trials in this project were 50.4kg/hour. However, these were very preliminary catch rates and will not be indicative of the catch rates the ROV will be capable of catching with an operator familiar with the ROV and fishing in an area with high density of scallops. If the catch rate can be increased the ROV also has the following advantages over dive teams:

- The ROV requires a single operator (compared to 4 divers) reducing the logistics of getting the crew together and operating
- There are none of the health and safety issues/restrictions associated with diving
- The ROV is not depth or time restricted as are divers and can fish scallops at depths from 1-100m depth for as long as it takes to fill the catch tray
- The ROV is as environmentally friendly as dive operations

4.4 Shell damage and sand ingestion

One of the marketing strategies of Norwegian companies in Frøya (eg Seashell AS) is to promote their scallops as being handpicked and in excellent condition. A visual comparison was made between scallops collected by the ROV and scallops collected by divers for Seashell AS (Figures 10, 11 and 12). The results show there was slightly more chipping on the growing edge of the scallop in the ROV collected scallops but the authors believe it would be very difficult to identify scallops collected using the two different techniques.

There were no obvious differences in shell quality in scallops collected by ROV compared to scallops that were handpicked by divers.

No comparison of sand ingestion by the scallops was made during the trials in Frøya. However, scallops currently collected by divers at Seashell AS are held in large plastic containers (Figure 17) which would be ideal for purging the scallops of excess sand.

In the trials in Helgeland observations showed no sand ingestion occurring due to improvements in catch efficiency of the ROV. The ingestion of sand is something that should be tested in any future trials.

Figure 17 The holding tanks used by Seashell AS to store scallops once they are landed.

4.5 Bycatch

The flora and fauna found at the test area used in Frøya is not atypical of the areas that are normally fished for scallops as it is a shallow site used to temporarily store scallops. Subsequently, there was an abundance of small echinoderms (particularly sea urchins) and algae. These items made up approximately 20% of the total catch at this site. None of the species collected as bycatch were damaged, or had any economic or conservation significance and were simply returned to the sea after capture. The authors believe that the level of bycatch would decrease significantly at most scallop collection sites as these sites would be deeper with a much less varied biota. The results in the 3rd trial in Helegland showed there was a very small bycatch consisting of only a few species. The bycatch consisted of ‘kuskjell’ (*Arctica Islandica*), a few starfish, a very few ‘o-skjell’ (*Modiolus Modiolus*), and some algae. Both the kuskjell (clam) and the oskjell (mussel) could be of commercial interest as they are both consumed as food.

4.6 Suggested improvements to increase ROV efficacy:

4.6.1 Protection of ROV

- Build in a protection system (fenders) for the ROV, and particularly the lower frame, to avoid damages when contact with the seabed, rocks etc.

- Build in a protection system for the nozzle to avoid damage to fragile parts such as the electronic actuators. Can be done partially by ensuring rake is not possible to lower into the seabed, by installing rubber “bumpers” between the nozzle and the ROV to reduce forces at impact, and partially by training; the more experienced the operator become, the less damage is likely to occur.

4.6.2 Monitoring:

- It is a challenge to identify the area that has been harvested and where this is in relation to the ships chart plotter. It will be imperative for efficiency to develop a monitoring system both for planning, execution and later documentation of the harvest. This system will consist of a location device on the ROV which will continuously send signals to the boat where a computer and a GPS calculates the data and processes the information into a map system so that the crew can see exactly where the ROV is operating and where it has been.

- We have modified the visual monitoring on the ROV; the main close-up camera is now located just above the nozzle both for scallop and sea-urchin harvest. In addition, a zoom camera is located on the top of the ROV. This camera will make it easier for the operator to plan where to go to next.

4.6.3 Modification of nozzles

- On the last trial on Helgeland there were issues with the nozzles clogging when we tried to suck in several scallops simultaneously. The nozzle does have some sharp edges and some bent corners which may be the cause for the clogging. Therefore, it will be necessary to make a smoother nozzle to avoid clogging. This will make the ROV far more efficient when harvesting on the high density areas on the edge between the shallow flats and the deeper fjords.

4.6.4 Launching and Recovery

- A launch and recovery System, LARS, using a hydraulically operated A-frame and an electric winch is required to operate the ROV at maximum efficiency. This would significantly improve the current clumsy and often dangerous operation required to launch the ROV with a normal crane.

4.6.5 Priority of development

All of the above suggested improvements cannot be achieved prior to final proof of concept of the ROV for either scallops, or sea urchins, or any other species. Once it is proven that the concept is feasible for commercial harvest of scallops, the list of improvements can be implemented which will further improve the efficacy of the harvest system.

5 Conclusions and recommendations

5.1 Conclusions

Catch rates improved significantly over the course of the trials as a result of the modifications and the increasing confidence of the ROV pilots. Therefore, the authors believe that the catch rates recorded in the trials are likely to be very conservative and should not be considered the maximum catch rates the ROV is capable of collecting.

The advantages of using the ROV over divers include the following:

- The ROV requires a single operator (compared to 4 divers) reducing the logistics of getting the crew together and operating
- There are none of the health and safety issues/restrictions associated with diving
- The ROV is not depth or time restricted as are divers and can fish scallops at depths from 1-100m depth for as long as it takes to fill the catch tray
- The ROV is as environmentally friendly as dive operations
- There were no obvious differences in shell quality in scallops collected by ROV compared to scallops that were handpicked by divers

5.2 Recommendations

- These trials have shown that it is possible to catch scallops using the ROV
- The modifications made to the scallop collecting system throughout the trials have made significant improvements in catch efficiency. However, further refinement is needed in order to increase catching efficacy
- In order to reach the target catch of 800-1000kg/day the catch rates recorded by the ROV would need to be doubled
- Further testing should be conducted in a commercial setting with a practiced ROV and a more suitable boat with and adequate mooring system to establish whether it is economically viable to utilize an ROV for scallop collection (i.e. double the catch rate)
- Economic comparison of running costs of ROV compared with a scallop diving team should be undertaken
- Test the efficacy of the ROV at various scallop densities and depths/sites
- Test for depuration efficacy trials on ROV caught scallops.

6 Acknowledgements

The authors would like to thanks all those participants in the ROV urchin and scallop projects. This was an involved project with some difficult logistical problems but due to the perseverance of the many that have been involved in the project, and the patience of the FHF funding body, the aims of the project were accomplished and this report has been completed.

7 Appendix 1: overall conclusions from ROV trial Part 1 and 2

7.1 Part 1: Sea urchins

7.1.1 General conclusions

The results of the current trial clearly show that the 7S-Technology AS SeabedHarvester ROV provides an effective method of collecting sea urchins in winter conditions in northern Norway. Over the six day fishing period the ROV performed reliably and without any technical problems. By using the ROV the dangers and logistics associated with diving operations during the winter months (limited daylight hours, extreme cold and poor weather conditions) can be avoided. The catch rates recorded in the study indicate that the ROV will be a more effective means of collecting sea urchins than using SCUBA divers in summer as well as in winter. However, the density of sea urchins present at any given site and the type of bottom terrain play an important role in determining the catch efficiency of the ROV and so it will be important to undertake preliminary mapping of an area prior to committing time and capital resources into ROV fishing.

Assuming that a cheap and reliable method for surveying the urchin density and substrate type in any given area is established then the use of the SeabedHarvester ROV has the potential to become a commercially viable method of sea urchin collection in both northern (and southern) Norway, particularly in areas where the conditions suit ROV collection (high sea urchin density on flat surfaces such as in Tromsø and Hammerfest). This in turn will provide continuity of supply to exporters which would lead to the development and expansion of the wild sea urchin fishery in Norway.

7.1.2 Advantages of the SeaBedHarvester ROV over dive operations

- The ability to fish during winter months.
- The ability to fish during severe weather conditions during other seasons.
- The ability to fish at greater depths than SCUBA divers can safely collect sea urchins.
- The ability to observe sea urchin densities and bottom terrain over relatively large areas quickly and effectively (the efficiacy of this would be greatly increased by the use of a small, mobile mini-ROV)
- The ability to fish for an extended time in single day (the logistics of getting a boat and crew can be maximized by spending longer days in the field with constant fishing activity whereas with divers the collection period is strictly determined by dive tables and the actual fishing time is restrictive).
- Higher daily catch rates than previous diver operations in the Båtsfjord area.

7.1.3 Recommendations to improve the efficacy of the ROV and commercialize it as a means of fishing sea urchin in Norway

- Modifications to the collection nozzle to improve collection efficiency and minimize environmental impact
  - The addition of a soft rubber rim around the outer rim of the nozzle
  - The addition of 200-300mm stiff plastic fingers to ‘sweep’ sea urchins from the substrate prior to being sucked into the ROV
- Use of a boat with the following properties:
  - Stable (e.g. a catamaran)
  - Low sides to accommodate easy handling of the ROV by a crane
  - Alternatively a specifically designed system for launching and retrieving the ROV from the stern of the vessel
  - Alternatively a method of collecting the sea urchins without having to remove the ROV from the water (e.g. an airlift pump to the water surface
  - Increased efficiency and power in the onboard generator to run the ROV smoothly and effectively
  - A reliable and effective winch anchor system (with a suitable anchor and chain arrangement) on both the bow and stern of the vessel
- A system of monitoring and tracking the position ROV in relation to the boat should be developed in order to effectively map the areas that have been fished and to allow the ROV operators to know they have effectively covered a given area
- A comparison of the cost efficiency (economic analysis) of fishing sea urchins with ROV technology compared with teams of SCUBA divers should be made in order to establish optimal fishing techniques for both winter and summer periods
- A system of fast and effective monitoring of any given fishing area needs to be established. This would enable the biomass of urchins present and the bottom terrain of any given area to be mapped so that the effectiveness of ROV fishing can be assessed prior to investing in the technology (the authors recommend the use of mini ROV’s).

7.2 Part 2: Scallops

7.2.1 Conclusions

The ROV trials showed that it is possible to fish scallops using the scallop catch system developed by 7S-Technology. Catch rates improved significantly over the course of the Trials as a result of the modifications to the ROV, the catch system and the increasing confidence of the ROV pilots. The authors believe that the catch rates recorded in the Trials are not the optimal catch rates that this system can achieve and are likely to be very conservative.

Currently, the ROV catch rates are approximately half the estimated viable catch rates and further trials are recommended to show whether sufficient improvements in the catch efficiency can be made to make this an economically viable scallop fishing technique.

7.2.2 *Advantages of using the ROV to collect scallops rather than divers*

- The ROV requires a single operator (compared to 4 divers) reducing the logistics of getting the crew together and operating
- There are none of the health and safety issues/restrictions associated with diving
- The ROV is not depth or time restricted as are divers and can fish scallops at depths from 1-100m depth for as long as it takes to fill the catch tray
- The ROV is as environmentally friendly as dive operations
- There were no obvious differences in shell quality in scallops collected by ROV compared to scallops that were handpicked by divers.

7.2.3 Recommendations

- The modifications made to the scallop collecting system throughout the Trials have made significant improvements in catch efficiency. However, further refinement is needed in order to increase catching efficacy are outlined in Section 4.6 of the attached Scallop Report
- Further testing should be conducted in a commercial setting with a practiced ROV and a **more suitable boat** with and adequate mooring system to establish whether it is economically viable to utilize an ROV for scallop collection (i.e. double the catch rate)
- Economic comparison of running costs of ROV compared with a scallop diving team should be undertaken
- Test the efficacy of the ROV at various sites around the coast of Norway that have varying scallop densities, depths and bottom terrains
- Depuration efficacy trials on ROV caught scallops should be undertaken

7.3 General conclusions

- A number of the recommendations from Part One (sea urchins) are repeated in Part Two (scallops) of this report. The main recommendation which is in both parts is the importance of using a suitable boat in any future ROV trials (for sea urchins or scallops). The requirements for the boat are clearly described in the attached report.
- It is important to consider that for the ROV to be commercially viable method of fishing it must be proven on a full commercial scale in a number of settings also reflect the wide variety of environments and wild populations of sea urchins and scallops that exist along the coast of Norway. The authors recommend that further trials be conducted:
    - On a suitable scale (to give realistic commercial outcomes)

- Should reflect the wide variety of environments and wild populations of sea urchins and scallops that exist along the coast of Norway (i.e.be undertaken at a number of sites along the coast of Norway)

- It is obvious from the bycatch during the trials that there is scope to collect other species using the ROV and this should be considered and investigated in the future

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