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

Part one: Report on Sea Urchin (Kråkebolle) collection trial

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Summary:
One of the major bottlenecks to the development of a sea urchin industry in Norway is a reliable and economically viable method of collecting urchins. The current trial aimed to test the economic feasibility of fishing commercial quantities of sea urchin during winter conditions in northern Norway using a modified ROV.
The results of the trial showed that in 4.5 days of fishing (excluding Day 1 and morning of Day 2) a total catch of 1.88 t was recorded with 34.9 % of the total catch (659,5 kg) consisting of export quality sea urchins (> 45mm test diameter). The authors suggest that the amount of sea urchins from the total catch that could be sold could have been increased to 52.1 % of the total catch (807 kg) by lowering the minimum size of the urchins that were landed to the industry recommended size of 40 mm test diameter and processing any damaged sea urchins to utilize the roe in these animals. The average daily catches for the ROV this was substantially higher (146 kg/day) than for previous dive operations in Båtsfjord (average 90.9 kg/day).
The results of the current trial clearly show that the SeabedHarvester ROV provides an effective method of collecting sea urchins in winter conditions in northern Norway and this method is likely to be more effective than using divers in summer as well as in winter. 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.

Norsk oppsummering:
En av de største flaskehalsene for utviklingen av en bærekraftig kråkebollenæring i Norge er en pålitelig og økonomisk forsvarlig fangstmetode for kråkeboller. Dette forsøket har hatt som mål å teste ut om det er mulig å fange kommersielle mengder av kråkeboller under vinterforhold i Nord-Norge ved bruk av en modifisert miniubåt (ROV).
Etter 4 ½ dagers fiske ble fanget til sammen 1,88 tonn kråkeboller ved bruk av ROV. Av denne fangsten var 659,5 kg (34,9 %) av høy eksportkvalitet (>45 mm skall diameter). Ved å sette en nedre grense på 40 mm, som markedet aksepterer, kunne hele 52,1 % (807 kg) av fangsten blitt solgt. Gjennomsnittlig daglig fangst ved bruk av ROV i Båtsfjord (146 kg/dag) var høyere enn det som tidligere er fanget ved dykking (90,9 kg/dag).
Resultatene fra dette forsøket viser at SeabedHarvester sin modifiserte ROV er en effektiv metode for fangst av kråkeboller under krevende vinterforhold i Nord-Norge. Videre er denne metoden trolig den mest effektive fangstmetoden under både sommer- og vinterforhold sammenliknet med dykking. Flere faktorer påvirker fangsteffektiviteten til ROV'en, som for eksempel individtetthet og bunnforholdene. For å få et mest mulig effektivt fiskeri ved bruk av ROV, er det derfor viktig å kartlegge kråkebollebestanden i området som det skal høstes fra i forkant av fangsten.

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1 Executive summary

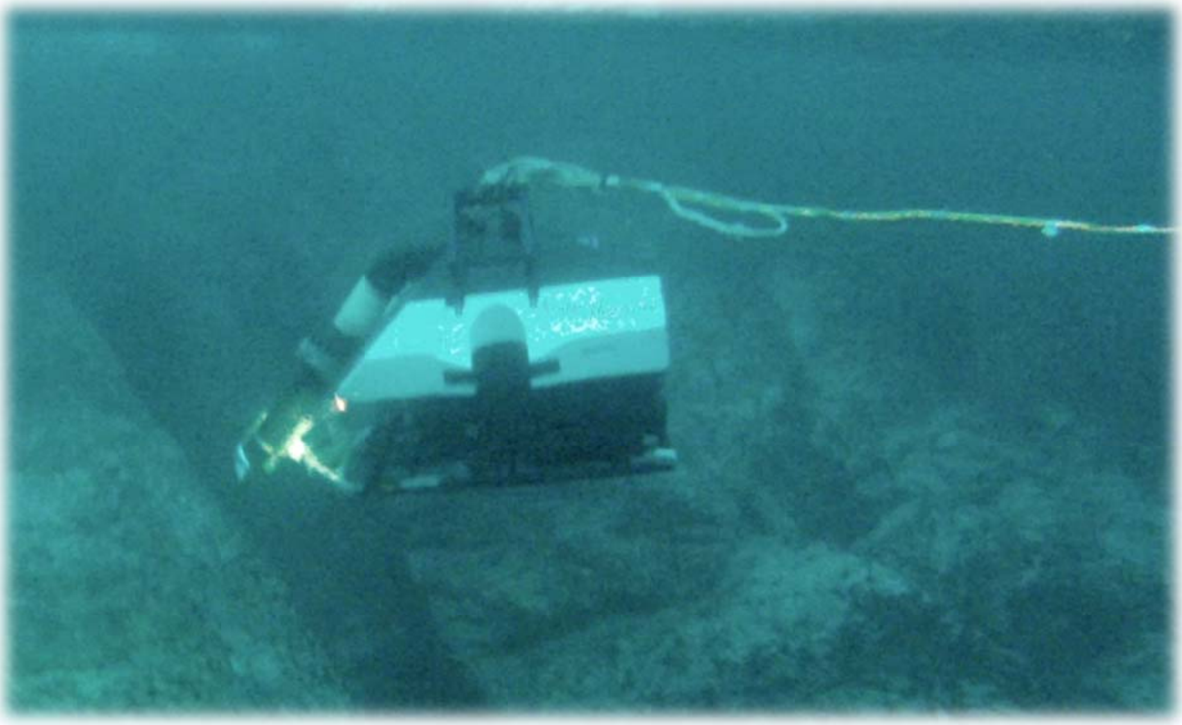
One of the major bottlenecks to the development of a sea urchin industry in Norway is a reliable and economically viable method of collecting urchins. Particularly in the north of Norway where conditions are extreme and diving is not feasible for at least 2-3 months in winter. The current trial aimed to test the economic feasibility of fishing commercial quantities of sea urchin during winter conditions in northern Norway using a modified ROV. The trial was conducted from 16-21 January 2012 in Båtsfjord.

The results of the trial showed that in 4.5 days of fishing (the first 1.5 days was spent looking at a number of different sites and selecting a site where the vessel could anchor) a total catch of 1.88 t was recorded with 34.9 % of the total catch (659.5 kg) consisting of export quality sea urchins (> 45 mm test diameter). The authors suggest that the amount of sea urchins from the total catch that could be sold could have been increased to 52.1 % of the total catch (807 kg) by lowering the minimum size of the urchins that were landed to the industry recommended size of 40 mm test diameter and processing any damaged sea urchins to utilize the roe in these animals. The by catch landed (30.8 % of the total catch) during the trial (the remainder of the catch was made up of small sea urchins) consisted primarily of mussels and sea cucumbers but there were small quantities of other benthic marine species present (see report for details).

Comparing the efficacy of the ROV catch rates to diver catch rates should ideally be done using the CPUE (catch of export quality urchins / minutes spent fishing). However, this data is not available for previous dive operations so in this study the average daily catches for the two methods were compared. For the ROV this was substantially higher (146 kg/day) than for previous dive operations in Båtsfjord (average 90.9 kg/day and with a high degree of variability).

The advantages of collecting urchins with the ROV include: the ability to operate in severe weather conditions throughout the year as well as in winter conditions; the number of crew required to run the ROV is less (1 skipper and 1 crew as shown in ROV scallop trials) compared to a dive crew (1 boat skipper and a minimum of 2 divers); there is potential for the ROV to spend considerably longer in the field than divers; the catch rates for the ROV were higher than for previous dive operations and are likely to increase with increased experience, the ability to locate suitable sea urchin fishing areas, modifications to the ROV nozzle and the use of a more suitable vessel. The results of the current trial clearly show that the 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. A series of conclusions and

recommendations are made in the report to maximize any future ROV sea urchin fishing operations.



The ROV in action underwater in Båtsfjord.

2 Introduction and Aims

There are a number of urchins species present in Norwegian waters but the most common species is the green sea urchin (*Strongylocentrotus droaebachiensis*). This species is known around the world for having roe of very high quality and extremely good taste and this is the species targeted for commercial harvesting in Norway. The most recent estimates put the sea urchin biomass along the Norwegian coast at 80 billion individual sea urchins (equivalent to 56,000 t) which constitutes a considerable and lucrative resource that is currently under utilized.

There have been numerous attempts to establish commercial sea urchin fishing ventures in a number of different areas around the coast of Norway. The largest of these was ScanAua AS which operated in Hammerfest between 2001 and 2010 and at its peak was collecting 30t of sea urchins from the wild per year. Currently there are a relatively few companies collecting urchins along the coast of Norway and Norway Sea Urchins AS is landing the largest quantities in the Båtsfjord area. Despite the relatively small scale of the industry at the moment there is considerable interest in collecting sea urchins from other areas around Norway.

The development of a sea urchin fishing industry in Norway has been intermittent and slow due to a number of recognized bottlenecks. The most critical of these has been establishing effective techniques for harvesting of sea urchins in the severe environmental conditions (restricted light, cold seawater and air temperatures, and severe winds) that are present, particularly in northern Norway. The traditional method of sea urchin collection has been to use dive teams and this has proved to be expensive, logistically intensive, extremely difficult and at times dangerous. In northern Norway it has been impossible to fish for sea urchins using divers in the middle of winter when conditions are at their most extreme. Regularity of supply is critical when supplying high quality live, or fresh, seafood and the difficulty collecting sea urchins in Norway has meant that the supply has have been intermittent and inconsistent in the past.

Alternative methods of capturing sea urchins have been attempted such as trapping and dredging but to date these methods have also not been shown to be effective. An alternative is the use of a remote operated vehicle (ROV) which has been specifically designed to collect benthic marine species. The advantages of the ROV include: the removal of divers, making operations logistically easier, and removing the danger aspect associated with commercial diving; the ability to collect urchins without inflicting environmental damage; and the ability to operate in the severe conditions found in northern Norway. The ROV has previously been tested in summer conditions at Hammerfest (Nofima Report: Fangst av Kråkeboller ved bruk av ROV) and a comparison was made between the quality of the sea urchins collected using divers compared to those from the ROV. The results show no difference in quality between urchins collected by the two methods. From this previous trial we know that the ROV is capable of fishing sea urchins but it’s efficacy in winter conditions, and in a commercial setting have not been tested.

Therefore, the aims of this trial were as follows:

- Test the efficacy of fishing commercial quantities of sea urchins
- Test the efficacy of the ROV in a winter conditions in northern Norway and in a variety of sites and bottom types
- Compare the effectiveness of the ROV with previous dive operations in the same area
- Make a series of conclusions and recommendations regarding the future use of ROV's in the sea urchin industry in Norway

3 Methodology

The SeabedHarvester ROV (see Figure 1) used in 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 (165 cm long x 96 cm wide x 110 cm high, 460 kg, running off single phase 230 VAC power source) with a control unit (including monitor: 96 cm long x 53 cm wide x 63 cm 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 catching tray (capacity approximately 100 kg, or 240 litres) which slots into the body of the ROV. A thruster creates the suction required to suck sea urchins from the sea floor, into the catch 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 (200 mm diameter) with a blunt rounded end. During the trial period in Båtsfjord a temporary adaptation was added to the nozzle to make it more effective and that will be discussed in greater details later in the 'Results - Catch effort and Catch per Unit Effort (CPUE)' section .

The SeabedHarvester ROV was transported from Frøya to Båtsfjord in Week 2 (2012) and was unpacked and prepared on 14/15th February. The aim of the trial was to use the ROV to fish for urchins from Monday (16th) to Saturday (21st) February and then unpack the ROV, download and organize the data files and have a final briefing on the weeks fishing prior to departure on Sunday 22nd February.

The set up of the ROV went smoothly and it was transferred onto the vessel R.V. Annabelle on Sunday 15th January. The control units were successfully installed in the wheelhouse and at approximately 9.00 am on 16th Feb the vessel left Båtsfjord to commence fishing. The R.V. Annabelle is a 14.9 m, 80 tonne fishing vessel with a crane situated on the aft deck (Figure 2). It has no means of anchoring from a fixed winch anchors, instead it has two large (approximately 500 kg) anchors which were carried on the aft deck and deployed to hold the vessel in position.

Figure 1 The ROV being lifted from the water (top), with a full catch tray removed for emptying (middle), and a close up of the collection nozzle extending from the front of the ROV for collecting urchins (bottom).

Figure 2 *R.V. Annabelle (A) tied up alongside the wharf in Båtsfjord and the crane mounted on her rear deck (B).*

For the following 6 days (including Monday 16th) the commercial potential of the ROV for fishing sea urchins was tested in Båtsfjord. The fishing sites were selected to accommodate weather conditions at the time, the sea urchin fishing license of Norway Sea Urchin (see Figure 3) and the ability to be able to securely anchor the vessel in position.

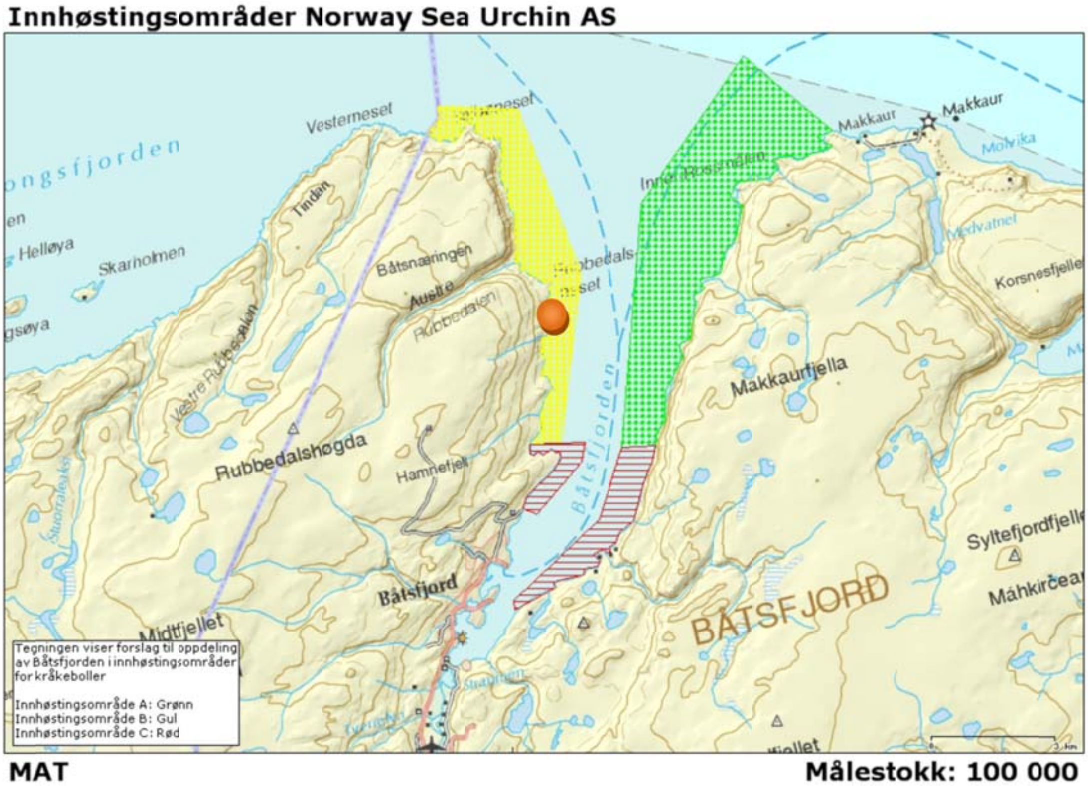


Figure 3 *Areas in Båtsfjord (shaded yellow, red and green) that Norway Sea Urchin AS has a license to collect sea urchins from (the orange point indicates where the majority of the fishing was done during the ROV trial in Båtsfjord).*

Once the vessel was securely anchored in position the ROV was deployed using the deck crane (Figure 2 and 4) and the umbilical line was monitored and deployed by hand. The ROV driver (Tor Andreassen) had no previous experience collecting sea urchins using an ROV but did have extensive experience driving large ROV's on oil rigs. Therefore, he was able to adapt to the smaller Seabed Harvester ROV quickly and efficiently (Figure 5).

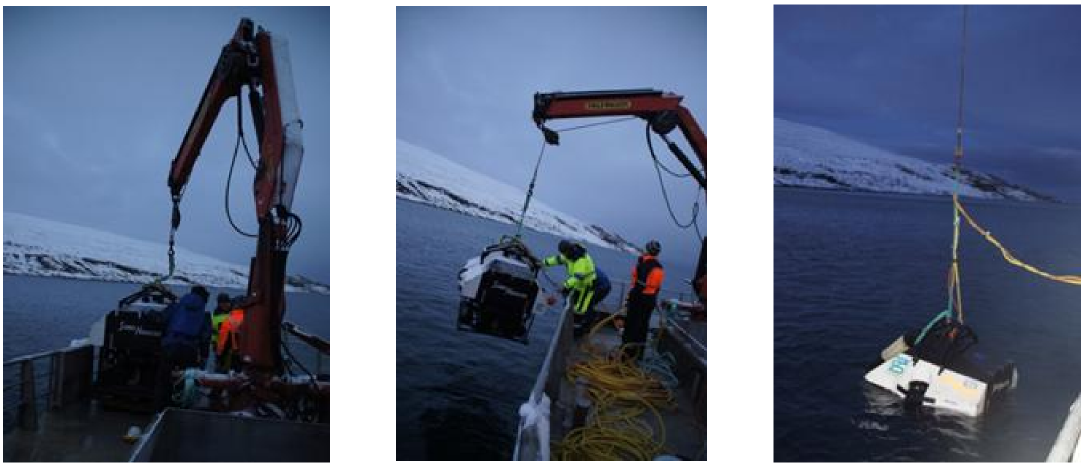


Figure 4 The ROV being launched over the side of the R.V. Annabell.

Figure 5 The ROV driver (Tor Andreassen) at the controls of the ROV in the wheelhouse of the R.V. Annabelle and the control monitors used during dive operations.

Each fishing day consisted of preparation and checking equipment prior to departure at approximately 8:00–8:30 am for the 1hr boat trip to the fishing sites (the maximum speed of the R.V. Annabelle was 8 knots). Fishing normally continued until approximately 16:00-17:00 when the ROV was secured on-deck and the return journey was made. On day 2 and 3 the entire catch was returned to shore and sorted for size and quality. The catch was sorted into the following categories:

1. Export quality sea urchins (> 45mm test diameter)
2. Small sea urchins (< 45mm test diameter)
3. Damaged sea urchins and by-catch.

On days 4, 5 and 6 the catch was sorted onboard and the quantities within each category were estimated. Small sea urchins and all by-catch were returned to the seafloor at the fishing site. Examples of the main types of by-catch were photographed and an estimate of composition of the by-catch was made at the conclusion of the trial. Video footage was made for each of the ROV dives and was used to determine the bottom substrate type (See Appendix One for examples of substrate types). A catch per unit effort was calculated by dividing the total daily catch (kg) by the total time (minutes) spent diving that day.

Following the 6 days of fishing the ROV was demobilized and unpacked and a debriefing was held prior to the team members dispersing on Sunday 22nd Feb.

4 Results and Discussion

4.1 Collection sites sampled

The date of collection, the air temperature and wind conditions, the position of the collection sites (GPS position) and a brief description of the terrain at each site are listed in Table 1. Day one, and a short period in the morning of Day two were spent on the western side of Båtsfjord where very few sea urchins were found above 25 m depth and those that were seen were present at very low densities. Anchoring at this deeper site was also difficult and the decision was made to shift to the eastern side of Båtsfjord for the rest of the week where there was shelter from the prevailing wind and it was possible to anchor closer to shore in relatively sheltered water.

Table 1 The locations (west or eastside of Båtsfjord and GPS), dates, weather conditions and bottom terrain at the sites for the 6 fishing days (16th – 21st Feb).

Date	Temp : Windspeed	Location	Bottom terrain
Day 1: *Mon 16th*	~-6 ^{o}C : 6 m/sec	West side	Steep, stony, rocky, large rocks with crevices
Day 2: *Tue 17th*	-6 ^{o}C : 3.4 m/sec	West side (am)	Steep, stony, rocky, large rocks with crevices
		East side (pm) N70^{o} 41.755 E29^{o} 48.322	Smooth surface, no large stones or boulders, remnant kelp beds
Day 3: *Wed 18th*	-6 ^{o}C : 16.0 m/sec (air temp est. -40^{o}C)	East side N70^{o} 41.830 E29^{o} 48.120	Smooth surface, no large stones or boulders, remnant kelp beds, high density mussel
Day 4: *Thu 19th*	-6 ^{o}C : 8.0 m/sec (air temp est. -40^{o}C)	East side N70^{o} 41.767 E29^{o} 48.340	Smooth surface with crevices, no large stones or boulders, remnant kelp beds, high density mussel
Day 5: *Fri 20th*	-6 ^{o}C : ~4.0 m/sec	East side N70^{o} 41.759 E29^{o} 48.341	Smooth surface with crevices, no large stones or boulders, remnant kelp beds, high density mussel
Day 6: *Sat 21st*	-8 ^{o}C : ~4.0 m/sec	East side N70^{o} 41.817 E29^{o} 48.111	Smooth surface, no large stones or boulders, remnant kelp beds, medium density mussel

4.2 Efficacy of fishing vessel (R.V. Annabelle)

As described in the methodology section, the R.V. Annabelle is a relatively large (14.9 m) and heavy (approx. 80 t) vessel. The anchoring system consisted of two very large and heavy anchors (Figure 6) that needed to be lifted into place with the crane situated on the aft deck of the vessel. The ideal anchorage to operate the ROV is to have an aft and a forward anchor that secures the ship in position with a minimum of movement. If a single anchor is used (forward or aft) the ship swings on the anchor making controlling and monitoring the ROV tether difficult. This restricts the operating distance of the ROV and increases the risk of entanglement around the rudder or the prop. The anchor system on the R.V. Annabelle made it very difficult and labour and time consuming to set and retrieve. Because of its weight and large size (creating large surface area that was affected by any wind) the R.V. Annabelle was also very difficult to maneuver. This made it very difficult to position the anchors so that the boat was securely anchored in the selected fishing site. Once anchored, the large wind area of the boat often caused the anchors to drag into deeper water and the vessel to drift off the fishing site, requiring the anchors to be reset. In addition, after an area had been covered by the ROV the ship needed to be repositioned and this also resetting the anchors. Fortunately, there were two highly trained skippers on board during the week (Ørjan Hansen and Tony Petterson) who managed to position the boat securely despite these difficulties.

Figure 6 *Picture of the large anchors (approximately 500 kg) used to anchor the A.V. Annabelle. Note the flat design of the anchor is more suited to digging into soft bottoms and the lack of anchoring chain which made the anchors very difficult to hold in position in shallow rocky sites.*

Once the ship was anchored in position the ROV was deployed using the crane on the aft deck. During the fishing trial the launching and retrieving went smoothly although it was a very high sided vessel with a 1 m high rail so the ROV needed to be lifted 4-5 m above the water level in order to launch or retrieve it. In rough seas this operation may prove difficult from this vessel.

Obviously the R.V. Annabelle was not the ideal boat to operate the ROV from and this will be discussed in greater detail, together with recommendations on what type of boat would be more suitable in the ‘Discussion’ section. What is evident is that there was a substantial amount of time spent maneuvering the boat and positioning the anchors which means the time spent fishing (and subsequently the total catch for the fishing period) reported from this study is a very conservative estimate.

4.3 Environmental conditions

The conditions experienced during the fishing period (16 - 21 Feb) were typical of the winter fishing season in the north of Norway and particularly around the Båtsfjord area. Conditions ranged from air temperatures of between -6 and -11 ^{o}C with wind speeds varying between 3.4 to 16m/sec. At the highest windspeeds (16 m/sec), it is estimated the windchill would have dropped the temperature as low as -40 ^{o}C (on Wed 18 Feb). Throughout the week the daylight hours where restricted to approximately 3-4 hrs of daylight during the middle of the day and the seawater temperature throughout the week was 4 ^{o}C. The sea urchins were fished between depths of 6-25 m with most of the catch being made below depths of 10 m.

These conditions would be extremely challenging and difficult for divers to successfully operate with the extreme cold, limited light and the depth that the sea urchins were concentrated at. This is an important consideration in the findings from this study as one of the primary aims was to test the efficacy of the ROV for fishing sea urchins in 'winter' conditions when it would not be possible, or would be extremely challenging to use divers to collect sea urchins.

4.4 Catch rates

The catch rates varied over the 6 days of fishing in Båtsfjord (See Table 1 and 2) depending on the presence/absence of sea urchins and the complexity of the bottom terrain at the fishing site. A number of the dives (or a considerable part of the dive), particularly in the first two days fishing, were used to investigate whether urchins where present or not and what their distribution was at a site. This reduced the catch rates during these dives (and some of the dives on subsequent days) and this should also be taken into account when calculating the efficacy of the ROV for sea urchin fishing as the catch rates estimated in this report will be very conservative.

Day 1 was spent on the eastern side of Båtsfjord where the urchins were difficult to find, anchoring the boat was difficult in the deeper water and the skipper and ROV driver acclimating themselves to the boat and ROV. Subsequently, the catch rate was very low this day. On Day 2 two more exploratory dives were made on the exposed eastern side of Båtsfjord in deeper water (> 25 m) before the decision was made to shift to a sheltered site on the western side of Båtsfjord where it was possible to anchor the boat in relatively shallow waters. Relatively high densities of sea urchins were found almost immediately and this area (approximately 0.5 km stretch of coastline) was fished for the remainder of the trial. The poor catches, the difficulty anchoring and the absence of urchins at the depths and sites that were selected on the eastern side of Båtsfjord on Day 1 and the morning of Day 2 show the importance of reliable mapping of an area for urchin presence/absence, urchin density and the type of substrate present in an area so that fishing effort with the ROV can be maximized.

Once the area on the western side was selected fishing progressed relatively efficiently, apart from the difficulties positioning the boat as previously described. On days 3 – 6 there were 6 dives made per day (except on Day 5 when there were only 5 dives) and on average (excluding 2 exploratory 10 minute dives on Day 3) these dives were just under 1 hr. (average dive time = 54 minutes, minimum dive time = 45 minutes, maximum dive time = 80 minutes) and the average catch per dive was 75.0 kg (for full catch data see Table 2). The catch rate during the dives varied (from 25 kg to 100 kg) depending mainly on the density of urchins found and the type of bottom terrain which dictated how easily these could be collected with the ROV. The catch rates improved throughout the 6 days of fishing as the skipper, crew and ROV driver became more proficient with the use of the boat and ROV. The fishing area proved to be suitable for fishing with the ROV.

The urchin's natural ability to 'stick' to a substrate differed between sites which made the collection easier at some sites compared with others. The urchins found at the fishing sites used on Day 2, 3, 4 and 5 were more securely fixed to the substrate than those at the dive location on Day 6. The terrain also differed between locations, and within a single dive site, affecting how securely the urchins were attached to the substrate. Some sites had many small crevices where the urchins appeared to be tightly packed and secure (Figure 7a). In contrast other areas were more open with flatter rocks and the urchins were easier to dislodge at these site (Figure 7b). Again, this highlights the need for an accurate assessment of the suitability of the terrain in a sea urchin fishing area as well as the biomass of sea urchins within the area in order to estimate the sea urchin biomass and fishing efficiency for any fishing venture in a particular area.

It should be noted that there are a number of areas along the Norwegian coast that would be even better suited than Båtsfjord for collecting urchins with an ROV. These include Hammerfest (see Nofima Report: Fangst av Kråkeboller ved bruk av ROV) and Tromsø (Figure 8) where there are high concentrations of good quality sea urchins on large flat substrate. Fishing with the ROV in these areas would be significantly easier which would result in higher catch rates and greater catch efficiency.

Table 2 *The number of dives, times spent underwater on each dive, the total catch (export quality urchins, small urchins and by-catch) for each dive made by the ROV during the 6 fishing trial (16th – 21st Feb). 'Eastern' and 'Western' indicates where the fishing occurred in Båtsfjord, and the switch between fishing the eastern and western sites is indicated by the orange line.*

Date		**Dive number**	**Time /water (minutes)**	**Catch (kg)**
Day 1: *Mon 16th* *Eastern*		1	40	1
		2	30	0,5
		3	10	0
Day 2: *Tue 17th*		1	25	0
	Eastern	2	55	1
	Western	3	45	60
		4	45	70
		5	50	50
		6	45	70
Day 3: *Wed 18th* *Western*		1	10	0
		2	55	80
		3	65	80
		4	65	50
		5	10	0
		6	45	25
Day 4: *Thu 19th* *Western*		1	60	50
		2	58	50
		3	55	90
		4	55	90
		5	40	100
		6	45	90
Day 5: *Fri 20th* *Western*		1	75	70
		2	65	90
		3	65	90
		4	55	90
		5	63	70
Day 6: *Sat 21th* *Western*		1	55	80
		2	80	90
		3	53	95
		4	69	90
		5	74	85
		6	60	80
TOTAL		32	1621	1887,5

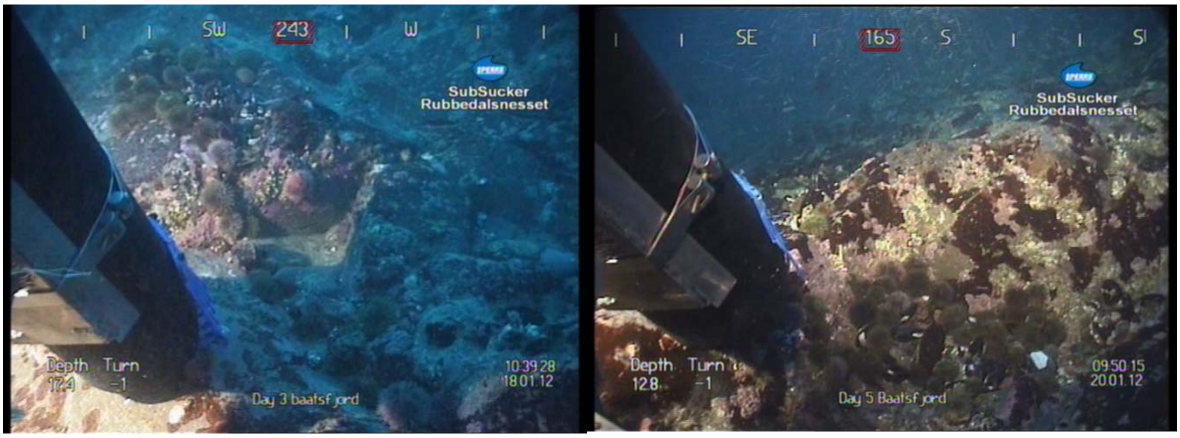


Figure 7a   Urchins situated in small crevices are more difficult to remove

Figure 7b   Urchins situated on flat rocks (smooth substrate) are much easier to remove.

Figure 8 Areas with high densities of sea urchins on flat surfaces are typical around Tromsø where the ROV would be an ideal method of collecting urchins.

4.5 Catch effort and Catch Per Unit Effort (CPUE)

One of the aims of this study was to estimate the fishing efficacy of the ROV compared to the traditional techniques (use of SCUBA divers) used in Norway. Table 3 shows the total time the ROV spent underwater per day together with the total catch landed per day and a breakdown of the catch (export quality; small sea urchins less than 45 mm test diameter; by-catch). The results show that in the 4.5 days of fishing (excluding Day 1 and the morning of Day 2 when exploratory fishing on the western side of Båtsfjord was being conducted) a total catch of 1.89 tons was landed and of the total catch 45 % (659.5 kg) consisted of export quality live sea urchins (see Table 3 and Figure 9). The CPUE calculated in Table 3 can be used to compare future results from other studies and from commercial operations where accurate catch and effort data is measured. The average CPUE (catch of export quality sea urchins/minutes spent fishing) increased throughout the 6 day fishing period and the average CPUE for the 4.5 days of actual fishing (half of Day 2 and days 3, 4, 5 and 6) was 0.45. On average the daily catch of export quality sea urchins during the current trial (for the 4.5 days of actual fishing effort) was 146 kg/day (daily catch = total catch 658 kg/4.5 days fishing effort).

Table 3 The total time spent underwater, daily total catch, amount of export quality urchins, small urchins and by-catch collected each day and the CPUE in Kg/min for the 6 day fishing trial (16th – 21st Feb).

Date	Total daily time u/water (minutes)	Total daily catch (kg)	Export Quality (kg)	Small urchins (kg)	By-catch (kg)	Daily CPUE (kg/min)
Day 1: *Mon 16th*	80	1.5	1.5	0	0	0.02
Day 2: *Tue 17th*	264	251	98	80	73	0.37
Day 3: *Wed 18th*	250	235	94	73	68	0.38
Day 4: *Thu 19th*	313	470	166	160	144	0.51
Day 5: *Fri 20th*	323	410	120	160	130	0.37
Day 6: *Sat 21st*	391	520	180	173	167	0.46
TOTAL	1621	1887.5	659.5	646.0	582.0	0.40
SUB TOTAL*	1461	1886.0	659.5	645.0	581.5	0.45

*(Excluding Day 1 and morning of Day 2)

(Note: The CPUE is calculated for the amount of export quality sea urchins landed, not the total catch landed)

The catch records from Norway Sea Urchin AS for sea urchin collections made by a team of two divers and one boat skipper from 1 August 2011 to 5 Dec 2011 (a total of 10 days collecting) show an average daily (a day was approximately 8 hours long) catch of 90.9 kg (± 16.4 kg) export quality sea urchins (minimum catch/day = 21 kg; maximum catch/day = 198 kg). The large variation in catch rates by divers (ranging from 21 kg to 198 kg/day) reflects the inherent difficulties with dive operations, even under relatively benign weather conditions. Unlike the ROV, divers cannot spend long periods underwater searching an area for sea urchins without seriously reducing the catch rates. In contrast, if an area has very high densities of urchin in relatively shallow water (the largest catch rates were recorded when the urchins had migrated into very shallow water in September 2011) then catch rates can be relatively high for dive operations.

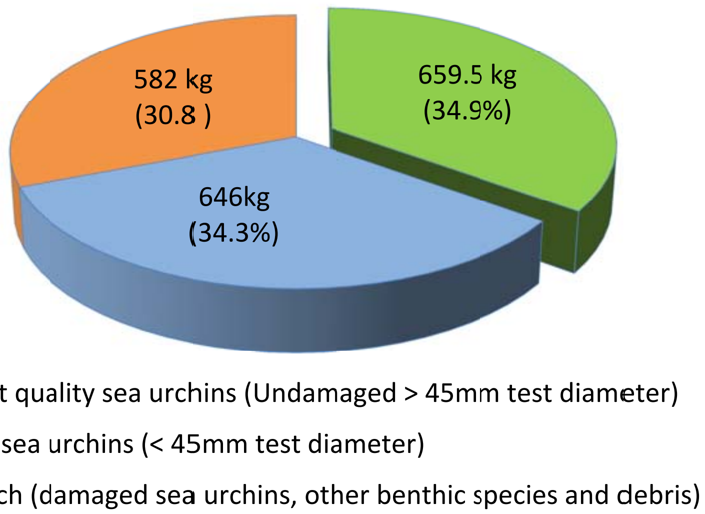


Figure 9 The quantity (kg) and % of the total sea urchin catch (in brackets) that was suitable for export, compared to the catch (%) and percentage of both small urchins and by-catch from the 4.5 day fishing period.

Ideally, comparing the efficacy of the ROV catch rates to diver catch rates should be done using the CPUE (catch of export quality urchins / minutes spent fishing). However, this data is not available for the dive operations so we can only compare the average daily catches for the two methods. For the ROV this was substantially higher (146 kg/day) than for previous dive operations in Båtsfjord (average 90.9kg/day but with a high degree of variability). Given the following: the number of crew required to run the ROV is less (1 skipper and 1 crew as shown in the scallop trials) compared to a dive crew (1 boat skipper and a minimum of 2 divers); there is potential for the ROV to spend considerably longer in the field than divers in future operation; that the catch rates for the ROV are likely to increase with increased experience, the ability to locate suitable sea urchin fishing areas and use of a more suitable vessel then these results indicate that ROV will be a much more effective means of collecting sea urchins than dive operations under most circumstances. There will be occasions (e.g. when large numbers of sea urchins are present in shallow water) when dive operations may be as effective as the ROV.

Currently Norway Sea Urchin AS is exporting sea urchins greater than 45 mm test diameter. However, it is possible to export smaller sea urchins than this (down to 40 mm test diameter) and this would have increased the catch efficiency of the ROV as there were a substantial number of urchins just under the 45 mm limit that were thrown away (either as waste product on Days 1, 2 and 3 or over the side at the fishing sites on days 4, 5 and 6). Furthermore, the damaged sea urchins (Figure 10) landed during the fishing trial were discarded as waste product, despite having a high gonad index and very good quality roe. An estimate of the quantity (kg) and % (in brackets) of the total sea urchin catch landed in the 4.5 days of fishing that was suitable for export and or processing (which included the export quality urchins, urchins between 40 – 45 mm test diameter and damaged urchins) showed that just over half (52 %) of the total catch has the potential to be used as marketable sea urchins (Figure 11).

It may be possible to significantly reduce the amount of damage to the urchins that are collected using the ROV by making some simple modifications to the end of the nozzle. During the trial a makeshift addition was added to the nozzle tip (see Figure 1) but a purpose designed addition, including a rubber rim on the end of the nozzle and a series of plastic fingers extending from the end to 'brush' the urchins off the substrate would increase its ability to collect urchins in crevices as well as on flat substrates without damaging them.

Figure 10 Example of damaged sea urchins that were discarded due to damage from the ROV and subsequent handling. These urchins still contained roe of suitable quality for export despite the exterior damage.

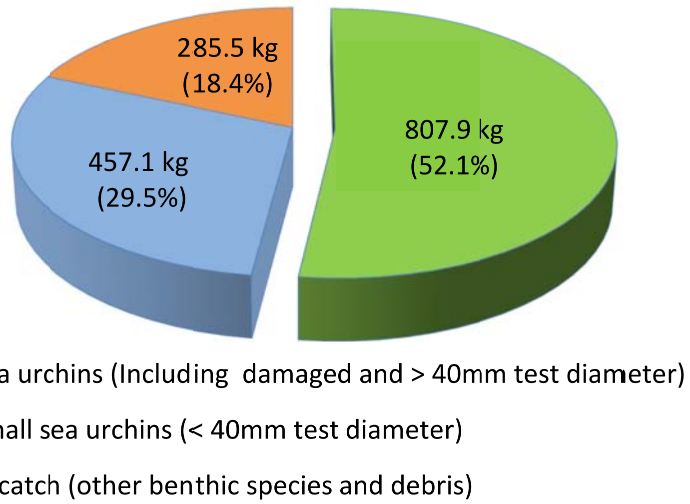


Figure 11 *The 'estimated' quantity (kg) and % of the total sea urchin catch (in brackets) that would be suitable for export and/or processing if the catch size was reduced to 40 mm test diameter and damaged sea urchins were processed, compared to the catch (%) and percentage of both small urchins and by-catch from the 4.5 day fishing period.*

4.6 By-catch and environmental effects of ROV fishing

Thirty percent of the total catch during the 4.5 days of fishing consisted of by-catch. This included a range of invertebrate species and a few finfish species (Figure 12 and 13) but most of the biomass of the by-catch consisted of mussels and sea cucumbers (an estimated 80 – 90 %). On Day 1, 2 and 3 of the trial by-catch was landed at the Norway Sea Urchin AS facility and sorted on land. On Days 4, 5 and 6 the by-catch was sorted at sea and returned to the site where it was caught.

One of the benefits of using an ROV is that it is less harmful on the environment (bottom substrate) than many other forms of fishing such as dredging and potting. However, there is still some impact, as demonstrated by the amount of by-catch collected during this trial. The authors believe this impact is minimal on the substrate and associated flora and fauna because of the ability of the ROV driver to select the areas that will be fished prior to actually fishing. The level of by-catch could be reduced by further modifications to the nozzle of the ROV and this will be discussed in the 'Conclusions and Recommendations' section.

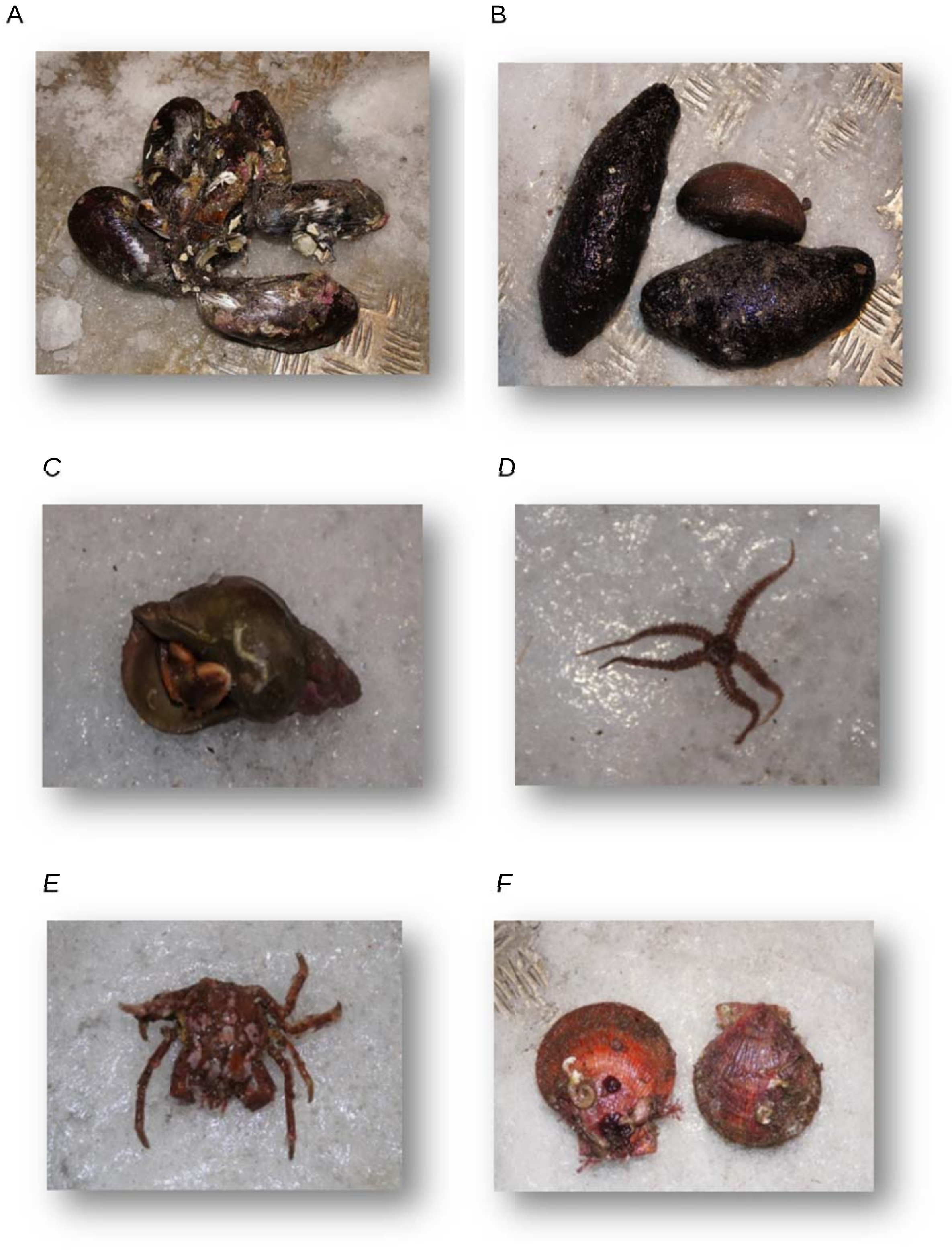


Figure 12 *The invertebrate species found in the by-catch included: A) mussels; B) sea cucumbers (these two species made up approximately 80 – 90 % of the by-catch biomass); C) gastropods; D) seastars; E) small crustacea (crabs) and F) small numbers of scallops.*

Figure 13 Examples of the vertebrate species found in the by-catch (these made up a very small % of the by-catch (< 0.1 %).

There are some areas in northern Norway where rare fauna have been identified such as in nearby Kongsfjord and Risfjord. In these fjords large areas of unusually old and large rhodolith (a crustose benthic marine red algae that resembles coral) have been observed and mapped (See Figure 14). However, none of these reef structures were observed in the fishing sites that were used during the fishing trial in Båtsfjord. The ability of the ROV driver to see the bottom prior to fishing, and for the driver to be aware of such fragile flora, will enable the ROV to avoid fishing in areas where any rare fauna may occur. Furthermore, it is highly unlikely that large concentrations of sea urchins would be found in areas where rhodolith corals are also found and so this conflict is unlikely to arise.

Figure 14 The areas of Risfjord and Kongsfjord that are known to have rhodolith coral growth and a picture of the rhodolith coral and associated fauna (pictures supplied courtesy of Kongsfjord International Scuba School).

5 Conclusions and recommendations

The results of the current trial clearly show that the 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 Seabed Harvester 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.

5.1 The advantages of the SeaBedHarvester ROV are as follows:

- 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 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.

5.2 Recommendations to improve the efficacy of the SeaBedHarvester ROV for future sea urchin operations:

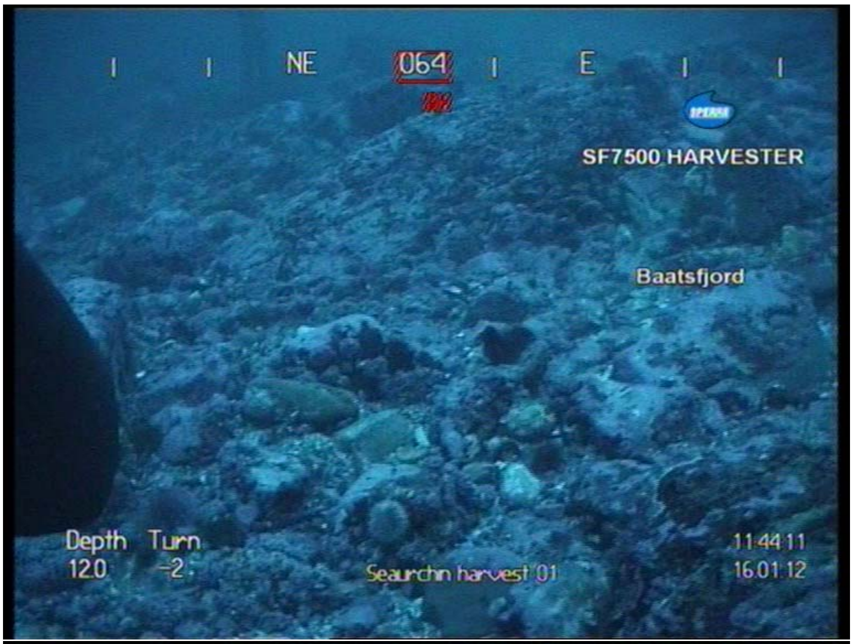
- Modifications to the collection nozzle to improve collection efficiency and minimize environmental impact
    - The addition of a soft rubber rim around the outer rim of the nozzle
    - The addition of 200-300 mm stiff plastic fingers to ‘sweep’ sea urchins from the substrate prior to being sucked 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 over the side by a crane or a novel system for launching and retrieving the ROV from the stern of the vessel

  - A reliable and effective winch anchor system (with a suitable anchor and chain arrangement) on both the bow and stern of the vessel
  - 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)
- 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).

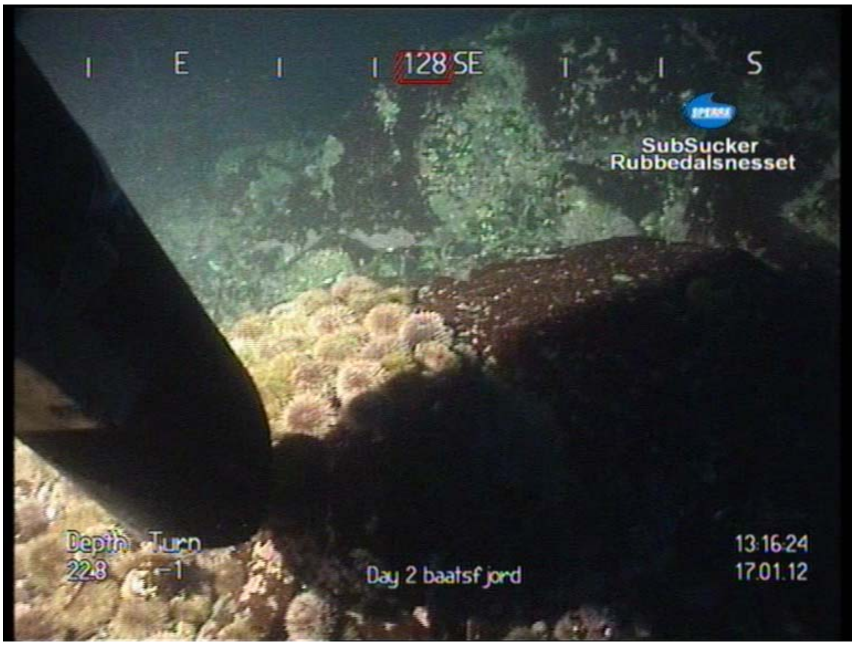
Appendix One

Images taken of the typical bottom terrain encountered on each of the 6 days fishing. Note the terrain varied considerably between days and also within dive sites.

Day 1

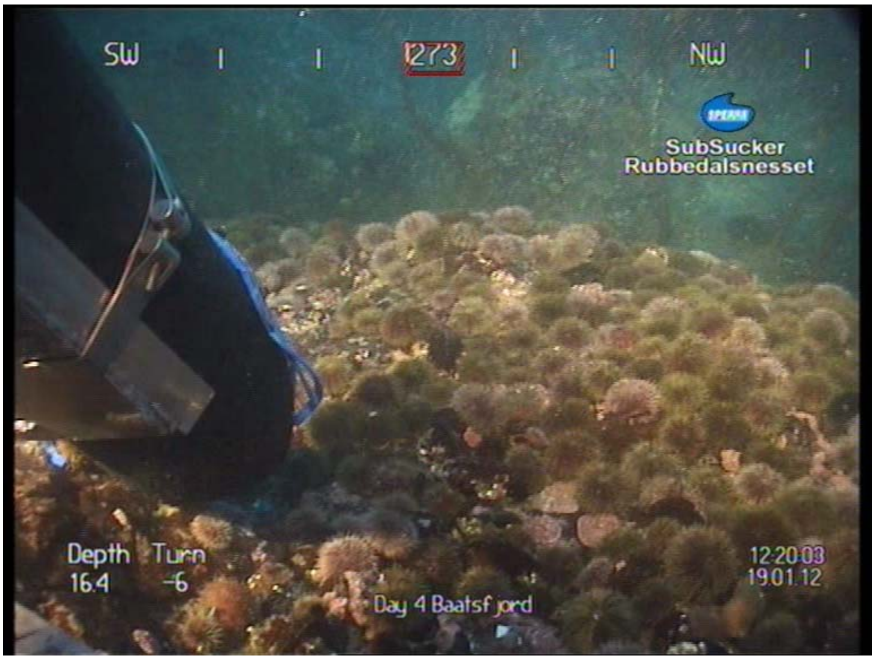


Day 2: (Appendix One continued)

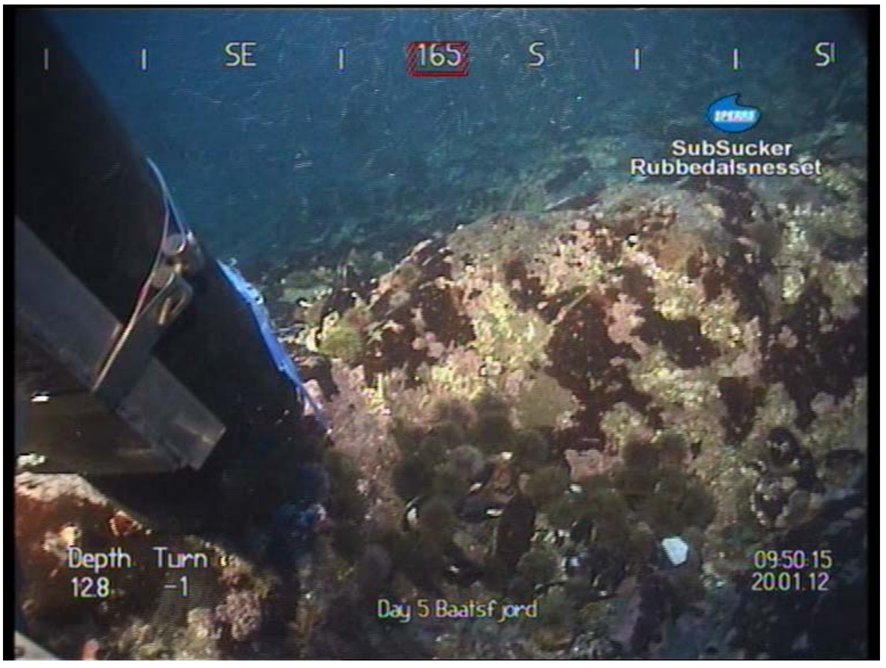


Day 3: (Appendix One continued)

Day 4: (Appendix One continued)



Day 5: (Appendix One continued)



Day 6: (Appendix One continued)

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