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# Environmental impacts of the diver operated C disc to harvest sea urchins and for kelp restoration

Norwegian Institute for Water Research

# REPORT

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Summary

NIVA did a 2-day environmental evaluation of the diver operated suction device “C disc” constructed by C robotics. Because the C disc uses suction from a water pump to suck sea urchins from the seafloor, it will collect bycatch and may have some harmful effects on the seafloor. It can also be used for kelp restoration in northern-Norway. This survey tested the C disc at two sea urchin barren grounds around Tromsø (Ytre Kårvika, Kvalsundet and Berg, Balsfjord) in May 2021. Analysis of catch efficiency on target sea urchins, bycatch and effects on the sea floor using video transects and frame counts was done at both sites. About 81 – 89 % of the catch consisted of the target species sea urchins and the CPUE was on average 78 ind./min (61 – 96 ind./min). Of these 11 % were damaged by the C disc. Bycatch accounted for 11 and 19 % of the catch and reflected the local community consisting of mainly larger loose sitting organisms. There was little to no damage observed on bycatch organisms, except for barnacle and blue mussels. There was a reduction in loosely fastened organisms after using the C disc, and the most impacted organisms reflected the bycatch. If the bycatch is kept in sea water and returned to sea soon after capture, they are likely to survive. The survey is only representative for hardbottom sea urchin barrens in northern-Norway.

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This report is quality assured in accordance with NIVA's quality system and approved by:

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# Environmental impacts of the diver operated C disc to harvest sea urchins and for kelp restoration

# Preface

This report presents the environmental impact survey of the C disc done for the project « Scalable urchin removal and kelp restoration technologies". The impact survey was conducted by NIVA for C robotics, Brace Inc. and Urchinomics. The project has been led by Helena Kling Michelsen in close collaboration with Hartvig Christie. Our main contacts at Brace Inc. has been Susanna Yip, and with Harm Kampen and Brian Tsuyoshi Takeda at Urchinomics. The field work and diving were done by Peter Leopold and Fagdykk AS. Helena Kling Michelsen assisted in guiding the fieldwork and diver, analysed the bycatch, did the video and photo analysis and wrote the report. Camilla With Fagerli planned the survey and analysed video and photos. Hartvig Christie planned the survey and contributed to writing the report.

Tromsø, December 2021

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# Summary

NIVA conducted a 2-day evaluation of the sea floor effects and bycatch from sea urchin harvesting using the diver operated suction device “C disc” constructed by C robotics. Because the C disc use suction from a water pump to suck sea urchins from the seafloor, it will naturally collect some bycatch and may have some harmful effects on the seafloor. It can also be used as a tool for removing sea urchins for kelp restoration in north-Norwegian waters. This survey tested the C disc at two sea urchin hardbottom barren ground localities around Tromsø (Ytre Kårvika in Kvalsundet and Berg in Balsfjord) in the end of May 2021. Analysis of catch efficiency on target sea urchins, bycatch and effects on the sea floor using video transects and frame counts was done at both sites.

About 81 – 89 % of the catch consisted of the target species sea urchins and the CPUE was slightly higher than other sea urchin harvesting tools with an average CPUE of 78 ind./min (61 – 96 ind./min). Of these, 11 % were damaged by the C disc. Bycatch accounted for 11 and 19 % of the catch and reflected the local community. The bycatch consisted mainly of larger loose sitting organisms such as snails, hermit crabs, blue mussels, sea cucumbers and algae. There was little to no damage observed on bycatch organisms, except for a few barnacle and blue mussels. The video transects and photos showed that there was a slight reduction in loosely fastened organisms after using the C disc, and the organisms that were most impacted reflected the bycatch. If the bycatch is kept in sea water and returned to sea soon after capture, they are likely to survive. The survey is only representative for hardbottom sea urchin barrens in northern-Norway.

As a harvesting tool on sea urchins the C disc was slightly more effective than other harvesting tools despite being diver operated and capable of a more targeted harvest of sea urchins. Although there was little visible bodily damage on the bycatch the amount of bycatch caught by the C disc was high and will need to be sorted from the catch and returned to sea at the site they were caught. This adds to both the cost and time when using the device and need to be addressed by future users.
As a tool for promoting kelp recovery the C disc was able to remove sea urchins to a low enough level on smooth seafloor without a lot of cracks and crevices. However, in Norway it does not seem to be the most cost-efficient method for achieving this goal, therefore it can be evaluated as part of a multi-method removal strategy for achieving sea urchin removal and thereby kelp restoration.

# Sammendrag

Tittel: Miljøundersøkelse på C disc som verktøy for å fiske kråkeboller og for tarerestaurering
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Forfatter(e): Helena Kling Michelsen, Camilla With Fagerli og Hartvig Christie
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NIVA evaluerte miljøeffektene til undervansstøvsugeren «C disc» som er produsert av C robotics. Ved å skape et sug vha. en vannpumpe kan C discen brukes av en dykker for å fangste kråkeboller til kommersielt bruk. Langs store deler av kysten i nord-Norge er mye av tareskogen blitt beitet ned av kråkeboller. Forsking har vist at tareskogen vokser tilbake om man fjerner kråkeboller, derfor er det mulig at c discen også kan bukes til restaurering av tareskog. Siden maskinen bruker vakuum sug kan den få med seg bifangst samt ha en negativ effekt på havbunnen den brukes på. Derfor ble C discen testet i felt for å se på effektene den kan ha på bunnfaunaen i nord-Norske kystvann. Testen ble gjort 26 – 27 mai 2021 på to kråkebolleørkener med hardbunn i nærheten av Tromsø (Ytre Kårvika i Kvalsundet og Berg inne i Balsfjorden). Vi evaluerte fangsteffektiviteten på kråkeboller, bifangst samt effektene på havbunnen ved å analysere videotransekter og fotorammer tatt før og etter C discen var i bruk.

Rundt 81 – 89 % av fangsten var kråkeboller og fangsteffektiviteten var høyere enn andre metoder for å fange kråkeboller (gjennomsnittlig effektivitet på 78 ind./min). Av disse kråkebollene var 11 % skadet. Bifangsten utgjorde 11 og 19 % av hele fangsten på de to stasjonene og bestod hovedsakelig av harde løstsittende organismer som snegler, eremittkreps, blåskjell, sjøpølser og ulike typer alger. Det var lite skade på bifangsten med unntak for noen knuste blåskjell og rur. Video- og fotoanalysene viste at det var en nedgang i løstsittende organismer på havbunnen. Hvis bifangsten holdes i sjøvann og returneres til havet i omtrent det samme området de ble fjernet fra er det en sjanse for at de kan overleve og bli en del av dyresamfunnet i kråkebolleørkenen igjen. Resultatene fra denne testen er kun relevant på hardbunn.

C discen er en effektiv måte for dykkere å fangste kråkeboller. Som en metode for å restaurere tareskogen er C discen i stand til å redusere kråkebollene til lave nok antall for at tare igjen kan vokse tilbake. Dersom restaurering er hovedmålet for å bruke maskinen er det ikke den mest kostnadseffektive metoden.

# 1 Introduction

With few natural predators, sea urchins (*Strongylocentrotus droebachiensis*) have grazed down large areas of kelp forest in Norway and turned them into urchin barrens (impoverished underwater deserts). Kelp forests have been estimated to provide ecosystem services valued to 500 000 - 1 000 000 USD/km coastline meaning that re-establishment of kelp forests will have a substantial value for the coastal regions, in addition to $CO_2$ binding, shelter for juvenile fish and recovery of an ecologically valuable biotope with high species diversity (Christie et al. 2009, Vásquez et al. 2014). The sea urchin barrens in northern Norway has lasted for 45-50 years. Recovery of kelp in most of this area will probably need human intervention to occur.

Shorter field studies have shown that mere removal of sea urchins is enough for kelp to regrow. NIVAS first study of sea urchins and kelp forest interactions in Tromsø in 2018-19 showed that kelp species such as *Alaria esculenta* and *Saccharina latissima* re-established inside and attached to net cages inside which the sea urchin density were kept at a minimum through manual harvesting by diving (Carlsson and Christie, 2019). Ironically, the kelp recovery was so substantial that after completing the trial, the weight of the attached kelp dragged down the cage nets, allowing the urchins to move back into the sea urchin harvested area. The success of this experiment is a result of keeping the sea urchins at a very low level inside cages and shows that removal and consistent efforts to keep sea urchins at low numbers is sufficient for kelp recovery. Similar success of rapid kelp recovery by removing sea urchins have been found further south (Leinaas & Christie 1996) and further north (Strand et al. 2020).

Sea urchin roe from *Strongylocentrotus droebachiensis* is a delicacy around the world. There is also an increasing interest in utilizing the sea urchins in alternative ways such as in pharmaceuticals, fertilizers and other uses. This makes sea urchins a targeted species for commercial harvesting in Norway. It was (however 11 years ago) estimated that there are 80 billion sea urchins (55 000 t) along the coast of northern Norway and thus a good potential to develop a sea urchin fishing industry (Gundersen et al. 2010). Traditional harvesting of sea urchins has used SCUBA dive teams to hand pick sea urchins. Diving is logistically difficult, expensive and inefficient. Some of the other fishing methods include trapping, dredging and remotely operated vehicle (ROV) with suction pumps. A new alternative is to use diver operated suction pumps previously used in oil and gas dredging for suction of sea urchins. This method could make dive teams more efficient at capturing sea urchins, utilize their dive times better and since divers are manually operating the equipment, they can target specific areas of the sea floor which other harvesting methods cannot do.

To be able to harvest sea urchins both in an economically efficient way, and at the same time promote kelp recovery/restoration in a sustainable manner, we addressed the following issues

1) test the efficiency of a modified diver operated pump based on those used in oil and gas dredging to “vacuum clean” the sea floor for urchins (i.e. how is it to operate and how low urchin densities are achieved with the method in different habitats, such as bedrock versus stony bottom),
2) asses the level of damage to sea urchins and the amount of bycatch caught by the pump,
3) assess the short-term impact of this harvesting technique on other benthic fauna species coverage and abundance.

Based on this initial trial, NIVA will assess the efficiency of the vacuum pump as a kelp recovery promoting tool, and the direct impact of the method on other fauna species abundance.

# 2 Methods

The C disc that was tested in this environmental study was a diver operated vacuum suction device specifically designed to collect benthic species such as sea urchins and to best optimize the dive-time. It is a modification of an existing subsea oil and gas dredging technology, used to clear construction sites of unwanted sediment and rocks. The C robotics team have adapted the nozzle, piping and flow to be powerful enough to vacuum urchins, but gentle enough that the urchins are not damaged.

When in use, the diver operates the suction nozzle which can easily be directed. The nozzle is attached to a reinforced PVC plastic hose with a diameter of 100 mm. The length of the hose can be adjusted based on the locality and depth. The hose is connected to a water diverter and the collection bag for the catch which floats at or close to the sea surface (Figure 1a). The removable collection bag has a capacity of approximately, 450 litres. Suction is created by a gas-powered water pump that is connected to the water diverter (Figure 1b). In the current survey three nozzles were tested, two round opening nozzles, one with a handle for the diver to hold, the other without a handle and a brush type nozzle (Figure 1c).


*Figure 1. The C disc components with (A) the fire hose, water diverter and the collection bag attached hanging in the water, (B) the water pump that provides the suction and the attached hoses and (C) the nozzles. Photos (A) and (C) by C robotics and photo (B) by NIVA (Helena Michelsen).*

The environmental survey was performed over two days, May 26th and 27th 2021. Two different sites were surveyed, spending one day at each site. The site localities were chosen based on bottom substrate, sea urchin density, proximity to Tromsø (Norway), and where the boat would be able to anchor safely for having divers in the water. Site one, Ytre Kårvika (point 1 in Figure 2), is a 4-5-meter-deep reef. Site 2, Berg, is a 1.5-2.5-meter-deep area with a varied bottom type (point 2 in Figure 2). Both days the C disc was operated by Fagdykk AS who served as skipper, deck crew, dive leader and safety team. Both days were spent aboard their diving boat MAXTOR. MAXTOR is a 15 meter long and 7-meter-wide vessel that has the capability of surface supplying two divers with air.

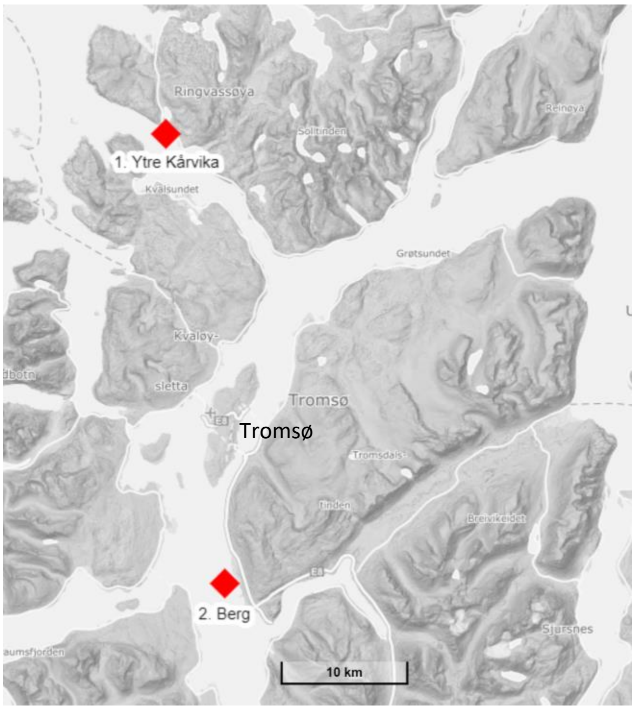


*Figure 2. Map of site localities, site 1 at Ytre Kårvika and site 2 at Berg. Maps gathered from norgeskart.no*

For the survey we used one scientific diver (Peter Leopold) to both video and photograph the transects as well as to operate the C disc both days. He is a highly experienced scientific diver and marine biologist who also holds the dive certificate that is required by Norwegian law to operate heavy underwater equipment such as the C disc. Three and two 9-meter-long transects covering 30 and 20 m$^2$ of the sea floor was surveyed at site 1 and site 2, respectively. Transect were marked by placing a 9-meter-long rope on the sea floor, securing the ends to the bottom and marking each meter on the rope with red tape markers. Using a GoPro camera and a helmet camera the diver filmed along the transects and photographed organisms within 50x50 cm metal frames placed at random along each transects. This was done before and after using the C disc along the same transect and provided qualitative and quantitative data on the short-term impact of this harvesting technique on seafloor organisms.

The C disc was used along the same 9-meter long transects by suctioning all sea urchins found within a 1-meter distance from the rope on one predefined side. The time (minutes) the C disc was in use was recorded. This way we knew exactly how many square meters was covered by the C disc and the duration it was in use.

When the C disc test was done at each site the whole catch in the collection bag was carefully emptied into a large square bucket with fresh sea water. Large organisms such as sea cucumbers were counted, examined for damage and thrown back to sea. The remaining catch was landed at Kårvika the research station of Akvaplan-Niva and stored in sea crates. On land the whole catch was analysed by counting the number of sea urchins caught, measuring the body size of a representative portion of the sea urchins (15 urchins) and counting number of dead and damaged sea urchins. Bycatch was also quantified by identifying them to genus, noting damage and counting. Since we had noted the duration of time the C disc was in use and counted the number of individuals of different organisms caught, the CPUE of different organisms was also calculated.

On the computer, the video transects and photo frames were qualitatively and quantitatively analysed before and after the use of C disc. The video transects were analysed by stopping the video every meter (red markers on the transect ropes indicated each meter). For each meter sea urchins and other organisms were counted, while organisms covering a larger area such as dead and alive algae, blue mussels and barnacles were noted as % coverage. This provided qualitative results. The same identification and counting routine was also performed for the photos of the metal frames, in order to calculate the average number of sea urchins and other organisms per $m^2$ before and after C disc use.

## 2.1 Survey sites and field conditions

The sites used in the survey were chosen to represent areas with high density of sea urchins and a bottom type that is likely to be suitable for kelp recovery. Site 1, Ytre Kårvika, is a 4 to 5-meter-deep reef of mainly smooth bedrock and some boulders (Figure 3A). Site 2, Berg (Figure 2), has areas of bedrock, rocks, small boulders and gravel/sandy bottom. There is also a more varied diversity at site 2 than at site 1, see section 3.4 for more details.

During the two survey days we experienced the strongest tidal currents of the whole year which caused several issues for the fieldwork. NIVA had a list of several potential survey sites that fit the requirements for the field work: bedrock and varied sea floor, high density of large sea urchins and a minimum of 3 meters for the boat to be anchored securely. On both survey days the preferred test sites was visited in the morning. However, we decided not to use these sites due to the severe currents making it nearly impossible for the boat to anchor securely and highly dangerous to have a diver in the water. This meant that a lot of time was spent both mornings in order to steam to the next preferred site (Ytre Kårvika and Berg).

The MAXTOR vessel is large and heavy. To securely anchor it in place requires 2 very large and heavy anchors set at the front and back of the boat. The anchor at the back of the vessel requires crane to be lifted into and out of the water. Only when the two anchors are securely and tightly fastened is it safe to have a diver in the water. Due to the strength of the current and a $180^{0}$ change in direction at mid-day both days the anchors had to be retrieved and reset several times. This made it difficult and time consuming to use the MAXTOR vessel. The currents were also an issue for the diver as it caused a strong drag on the suction hose he was operating.

The diver tried three different nozzles and found that the easiest and best one for collecting sea urchins was a round open nozzle with a holding handle. This handle made it easier to manoeuvre in between rocks. It provided the diver with the opportunity to move easily and be neutrally buoyant in the water column. The open nozzle without a handle was more difficult to manoeuvre while scuba diving, as it required two hands to operate. This nozzle appears to be better to use if the diver is walking on the sea floor (requiring another type of diving gear). Both open nozzles needed to be directed directly at the sea urchins or at a very slight angle to successfully dislodge and collect sea urchins. Interestingly, the brush nozzle which is designed to carefully dislodge the sea urchins from the sea floor by brushing before suctioning did not work very well. It was difficult to get the sea urchins to successfully dislodge and once they did dislodge, they were difficult to collect even after increasing the suction strength. This may be caused by several factors such as the strong currents making the sea urchins fasten themselves stronger to the sea floor, the sea floor structure, or that the suction opening is too angled away from the seafloor and thereby not creating enough suction onto the target organisms (urchins). We also discovered after the surveys that the water pump should be set to maximum strength in order to be more efficient. During this test we adjusted the suction strength based on the diver's feedback.

Some problems were encountered in the field. At site 1, 3 metal frames were photographed before and after using the C disc while at site 2, 5 photo frames were photographed. The reduced number of frames photographed at site 1 was due to time constraints caused by the strong currents and repositioning of the boat. The GoPro camera also froze and stopped working at site 1, so we were not able to film transect 1 and 2 post C disc use. Despite these problems the data gathered is enough to produce results and draw conclusions.

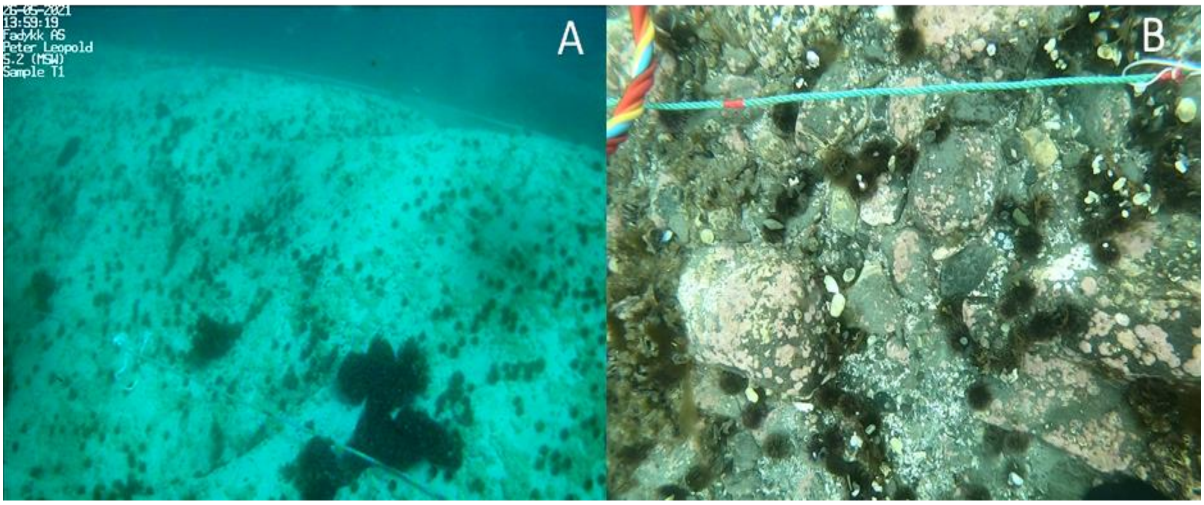

*Figure 3. The bottom type and structure at site 1, Ytre Kårvika (A) and site 2, Berg (B).*

# 3 Results

## 3.1 Sea urchin catch rates and damage

The catches on the two days varied, most likely due to different size structure, density of sea urchins and seafloor structure at the two sites. At site 1, the average density of sea urchins was 37.8 ind./$m^2$ (ranging from 16 to 86 ind./$m^2$). Here the C disc was in operation for 19 minutes covering an area of 28 $m^2$ and caught 1825 sea urchins with a CPUE of 96.1 ind./min (Table 1). A major part of the sea urchins at this site were small and below commercial value size at an average size of 32.5 mm (commercial size is 40-45 mm and larger). At this size the catch was approximately 18 kg (assuming that small sea urchins weigh on average 10 grams).

At site 2, the average density of sea urchins was lower than at site 1 with 26.8 ind./$m^2$ (ranging from 4 to 50 ind./$m^2$). The C disc was in operation for approximately 12 minutes covering 18 $m^2$ and caught 736 sea urchins with a CPUE of 61.3 ind./min (Table 1). At this site more sea urchins were of commercial size with an average test size of 47.8 mm, which corresponds to a catch of approximately 25 kg (using mean weight of 20 grams commonly used for commercial sized sea urchins).

The differing catch efficiency at the two sites may have been partly affected by sea floor structure. When viewing the video footage of the C disc in operation it appeared that sea urchins were easier to remove and collect at site 1 compared to site 2 where urchins seemed to be “stuck” on the sea floor. The seafloor structure likely affected how well sea urchins were able to attach to the substrate with their tube feet. The more varied terrain with a lot of cracks and crevices at site 2 appeared to allow sea urchins to be tightly and securely fastened and not caught by the C disc. While the flat bedrock at site 1 allowed for easier dislodgement.

*Table 1. The total time the C disc was in use, mean density of sea urchins at each site, mean size of sea urchins in the catch, number of individuals caught at each site and the CPUE in nr/min at each site during the two day environmental survey (May 26 – 27 2021).*

| **Site** | **Total time C disc in use (minutes)** | **Initial mean density (ind./m²)** | **Mean size (mm)** | **Sea urchin catch (nr. individuals)** | **CPUE (nr/min)** |
|---|---|---|---|---|---|
| Site 1 | 19 | 37.8 | 32.5 | 1825 | 96.1 |
| Site 2 | 12 | 26.3 | 47.8 | 736 | 61.3 |
| **Average** | 17.5 | 32.3 | 30.67 | 1280.5 | 78.7 |
| **Total** | 35 | | | 2561 | 157.4 |

About 10 % and 11 % of sea urchins caught with the C disc were damaged at site 1 and 2, respectively. Different types of damage were observed on the sea urchins. A majority had all or most of their spines ripped off, while others were completely crushed or had holes punctured (Figure 4). These sea urchins would not be of use in a commercial setting for roe enhancement.

*Figure 4 Damaged sea urchins caught with the C disc at site 1, Ytre Kårvika, May 26, 2021.*

## 3.2 Bycatch

Approximately 19 % and 11 % of the total catch consisted of bycatch at site 1 and 2, respectively. This included a range of different invertebrates but also algae, coralline algae, rocks and debris. Only the invertebrate species were counted and at both sites snails were the dominant bycatch, followed by hermit crabs (Figure 5 and Table 2). The species composition of bycatch reflected the local benthic community (see section 3.4 for details on local fauna). The bycatch organisms did not appear to have much bodily damage. The exception was at site 2 where some of the bycatch consisted of broken barnacles and blue mussels (not counted only noted, see Figure 5B).


*Figure 5. Bycatch at site 1 (A) consisting of mainly snails and at site 2 (B) consisting of mainly snails, blue mussels and hermit crabs. The glove and pencil provide an indication of size.*

At site 1, 91 % of the bycatch consisted of snails which also had a high CPUE of 20.53 ind./min (Figure 6 and Table 2). The other bycatch species contributed to less than two percent of the total bycatch (Figure 6). Despite the dominance of one species in the bycatch the variation of organisms caught at site 1 was higher than at site 2 and included landings of sea cucumbers, shrimp and red sea urchins which were not found at site 2. The C disc also caught two handfuls of red algae, some green filamentous algae and coralline algae (see lower left corner in Figure 5A).

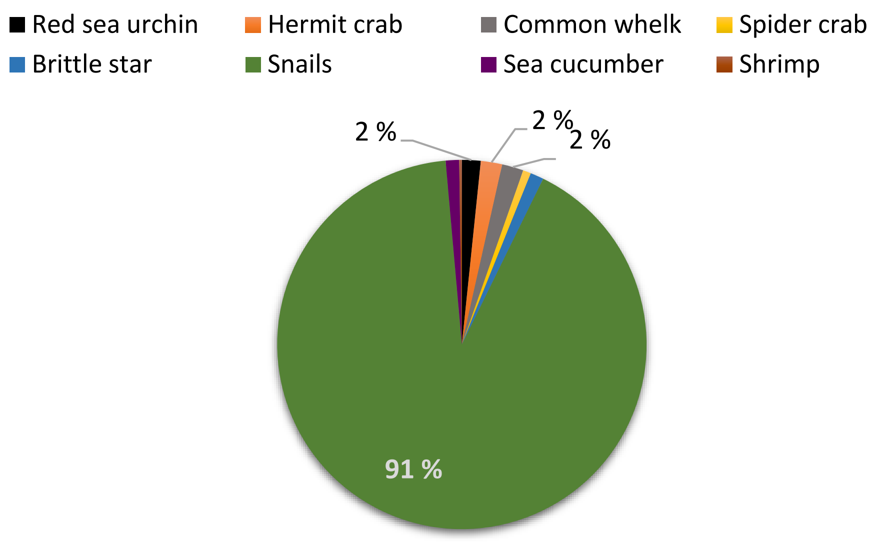


*Figure 6. Composition of bycatch caught by the C disc at site 1, Ytre Kårvika.*

Like at site 1, snails were also the dominant bycatch at site 2, contributing to 40 % of the total bycatch (Figure 7). Blue mussels were the second dominant bycatch contributing to 33 % of the total bycatch followed by hermit crabs at 18 % (Figure 7). The catch also consisted of 4 large rocks, two handfuls of green thread algae, debris and broken barnacles and blue mussels (Figure 5B and Table 2).

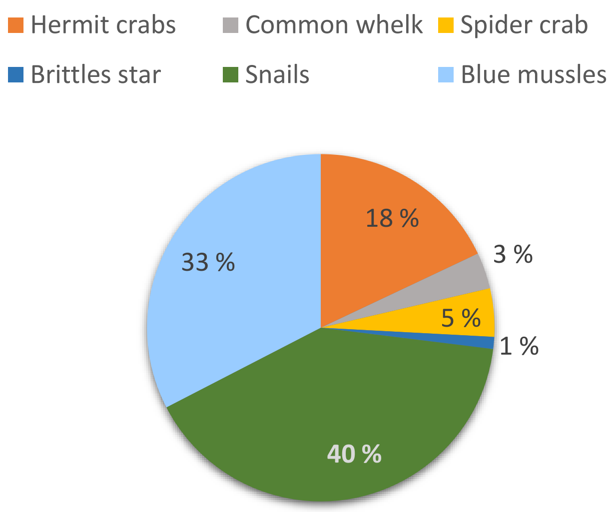


Figure 7. *Composition of bycatch caught by the C disc at site 2, Berg.*

*Table 2. Bycatch species at site 1 (Ytre Kårvika) and site 2 (Berg), number of individuals caught and CPUE (ind./min) for each bycatch species during the survey period May 26 – 27, 2021.*

| | Site 1 | | Site 2 | |
|---|---|---|---|---|
| **Species** | **Number ind. caught** | **CPUE (ind./min)** | **Number ind. caught** | **CPUE (ind./min)** |
| Snails | 390 | 20,53 | 36 | 3 |
| Hermit crab | 8 | 0,42 | 16 | 1,3 |
| Spider crab | 3 | 0,16 | 4 | 0,33 |
| Common whelk | 8 | 0,42 | 3 | 0,25 |
| Brittle star | 5 | 0,26 | 1 | 0,08 |
| Blue mussels | - | - | 29 | 2,42 |
| Red sea urchin | 7 | 0,37 | - | - |
| Sea cucumber | 5 | 0,26 | - | - |
| Shrimp | 1 | 0,05 | - | - |
| Red algae | Yes | - | - | - |
| Green thread algae | Yes | - | Yes | - |
| Coralline algae | Yes | - | - | - |
| Rocks and debris | Yes | - | Yes | - |
| Broken clams and barnacles | - | - | Yes | - |
| Average | 53,375 | 2,81 | 14,8 | 1,24 |
| Total | 427 | 22,47 | 89 | 7,41 |

## 3.3 Short term changes on local sea floor flora and fauna

The composition and density of organisms differed at the two sites. Prevalent organisms at each site were well reflected in the bycatch (section 3.3), yet some organisms were only found in the bycatch and not seen in the video transects nor photos. Changes in density and coverage of all organisms after C disc use were observed, especially those that were loosely sitting on the sea floor. Encrusting and fastened organisms appeared to be less affected by the C disc.

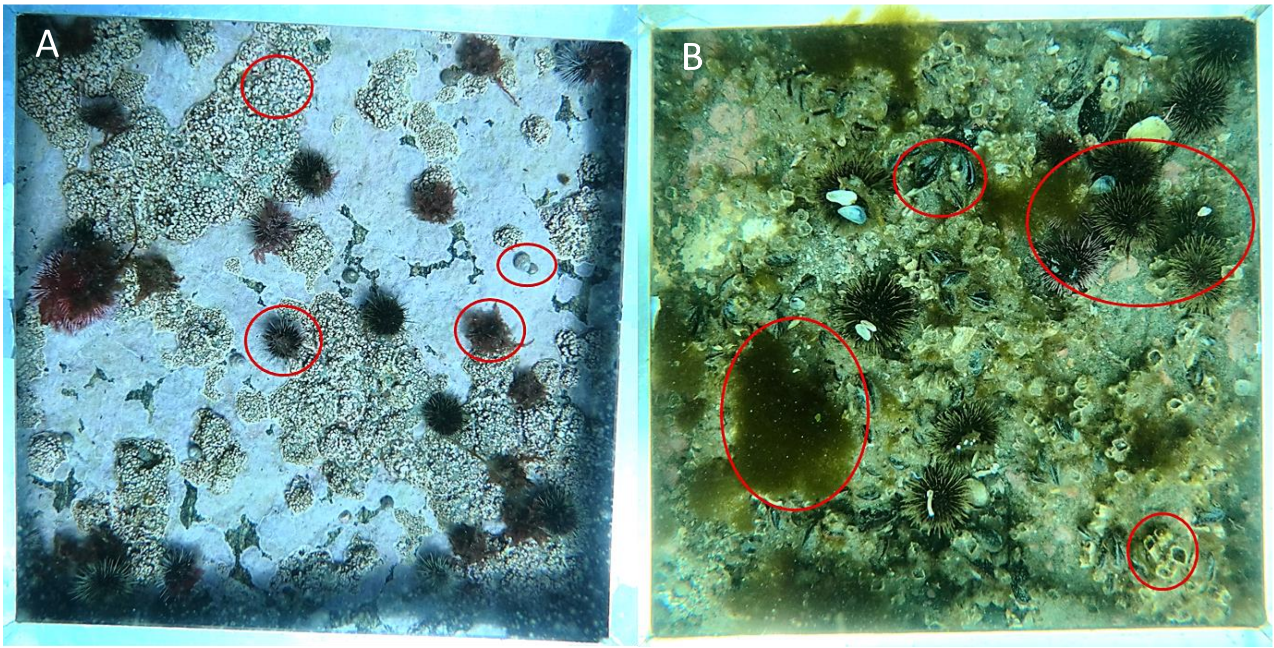

*Figure 8. Sea floor composition and structure at (A) site 1 and (B) site 2 prior to C disc use. The red rings indicate organisms such as sea urchins, snails/hermit crabs, tufts of green and red algae, coralline encrusting algae, barnacles and blue mussels.*

At site 1, the sea floor was dominated by snails/hermit crabs (it is difficult to distinguish the two on video and photographs). Other organisms were brown sea cucumbers, common whelks, blue mussels and various unidentifiable clams (Figure 8A). Coralline encrusting algae also covered much of the bedrock surface on all three transects at this site as well as small clumps of red algae and green turf/filamentous algae spread along the transect (Figure 8A).
The largest reduction in abundance at site 1 was the removal of the targeted species sea urchins (Figure 9A), where the average density prior to C disc was 37.8 ind./$m^2$ (ranging from 16 to 86 ind./$m^2$) and 10.4 ind./$m^2$ post C disc use (ranging from 0 to 21 ind./$m^2$). Some crushed sea urchins were still attached to the sea floor after C disc use (Figure 10), indicating that the lip of the nozzle may be a bit hard. Interestingly, by the time the diver returned to the first transect to film and take pictures post C disc use, the sea urchins had already moved into the cleared area, indicating that the reduction of sea urchins is potentially higher. Indeed, if this first transect is removed the new average sea urchin density prior to C disc is 42.8 ind./$m^2$ (± 11) and 3.3 ind./$m^2$ (± 1.9) after C disc.
Despite being the dominant bycatch there appeared to be only a slight removal of the dominant snails/hermit crabs with a reduction from an average of 26 ind./$m^2$ (± 11) to 20.7 ind./$m^2$ (± 7) (Figure 9A and 9B). Although there was a complete removal of sea cucumbers (initially 8 individuals seen along the video transects) 5 were found in the bycatch. Here the diver was able to prevent catching them by pushing them away. For the encrusting coralline algae there was hardly any reduction in coverage after using the C disc (Figure 9B). Clumps of red algae was reduced from an average of 13 clumps/$m^2$ to 7 clumps/$m^2$ or covering 13 % to 3.3 % of the sea floor before and after C disc use, respectively (Figure 9A and B).

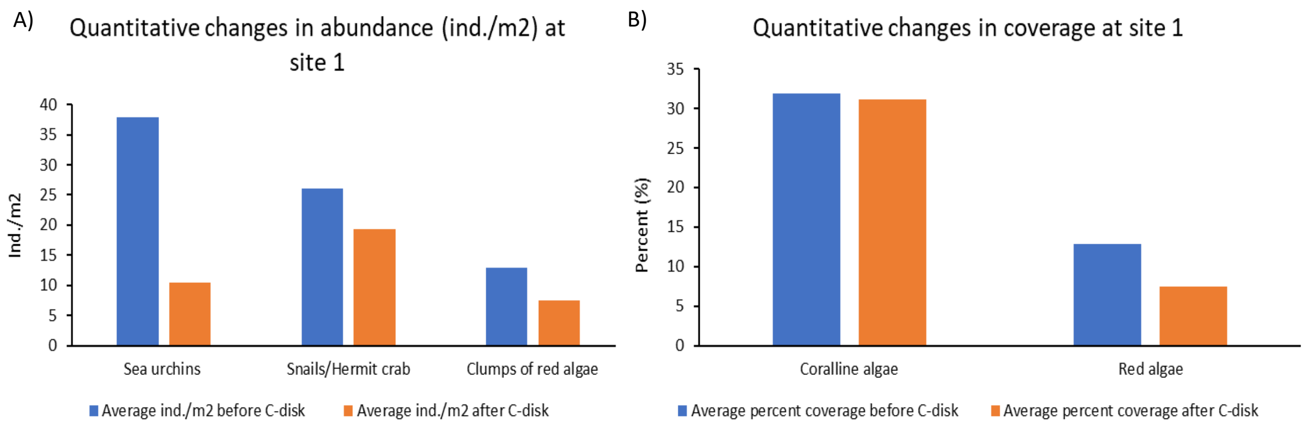


*Figure 9. The qualitative (A) average ind./m2 of sea urchins, snails/hermit crabs, sea cucumber and clumps of red algae, and (B) average percentage covered by coralline algae and red algae before and after using the C disc at site 1, Ytre Kårvika.*

*Figure 10. Grey circles around two crushed sea urchins still attached to the sea floor at site 1, Ytre Kårvika.*

Site 2 was dominated by barnacles and blue mussels. These organisms are found in very large numbers often covering large parts of the sea floor as they sit very close together or above each other, making it difficult to distinguish individual organisms. Therefore, they were noted as the percentage they covered the sea floor in the video and photo analysis (Figure 8B). Tufts of green algae were observed all along the transects. Some of these were large and covered other organisms from view. Other organisms at Berg included snails/hermit crabs, clams, sea stars, chitons and common whelk.
The highest removal was for the target species sea urchins, where the density was reduced from an average of 26.8 ind./$m^2$ (range 4 – 50 ind.$m^2$) to 0.6 ind./$m^2$ (0 – 4 ind./$m^2$). As mentioned in section 3.2, the removal of sea urchins is likely to be lower at this site as a fraction of the sea urchins were hiding halfway under rocks and in crevices after using the C disc (see Appendix Table 7). The change in percentage coverage of blue mussels and barnacles before and after the C disc had been used was low. Blue mussels was reduced from covering 36 % to 33.5 % of the sea floor while barnacles was reduced from 31 % to 30 % coverage (Figure 11). However, there were a couple of barnacles that were ripped off the rock they had been attached to (Figure 12), again indicating that the lip of the C disc nozzle is a bit too hard. The video transects showed a reduction in coverage of green algae from

21.6 % before C disc to 14.7 % after C disc (Figure 11). Due to sand being kicked up by the diver and the complex sea floor structure at site 2 it was difficult to identify and count all the other organisms after the C disc had been used.

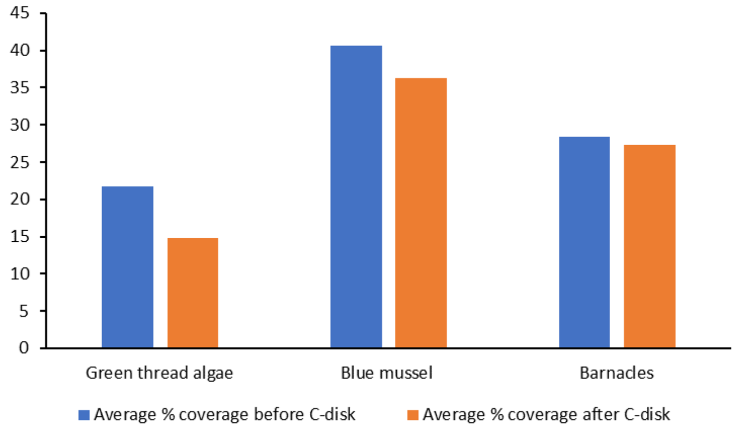


*Figure 11. The average percent coverage of green algae, blue mussel and barnacles before and after using the C disc at site 2, Berg.*

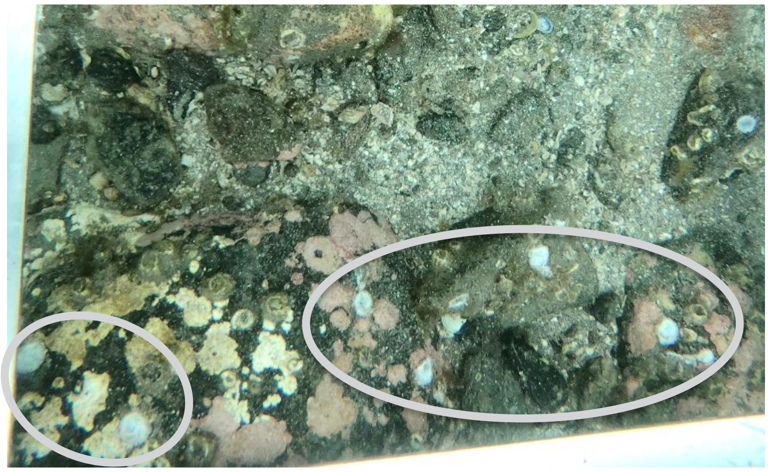

*Figure 12. Grey circles around white spots where barnacles have been ripped off the rock they were attached to at site 2, Berg.*

# 4 Discussion and recommendations

*Efficiency*

The results from this trial showed that the C disc is an efficient tool for vacuuming sea urchins. In a commercial setting a mean CPUE of 78.7 ind./min (1200 – 1900 kg/day) is slightly higher than other methods used for collecting sea urchins, such as trapping and SCUBA diving. The simple collapsible traps made by NOFIMA have an average CPUE of 165 ind./trap equivalent to 300-600 kg/day after a setting time of 5 – 7 days (James and Siikavuopio 2014); while experienced SCUBA divers picking sea urchins have a catch rate of 1000-1500kg/day (1250 kg/day on average). Although the catch efficiency is slightly higher than the other methods there is a considerably higher damage to the target species compared to traditional methods. There is also a considerable amount of bycatch caught by the C disc which need to be returned to sea at site. This makes the C disc less efficient in the field and adds to both the cost and time which needs to be considered by future users.
The CPUE effort varied at the two sites based on sea urchin density and seafloor complexity. Moreover, the C disc is not capable at size selection and will collect any sea urchin it comes across unless the diver works to avoid them. Since sea urchin density and size distribution is often patchily distributed on the sea floor it is important to properly survey areas prior to deciding where to focus efforts and thereby obtaining higher CPUE of commercially sized sea urchins. For this, surveying methods such as ROVs, drones or snorkellers can be used.

*Surface type*

The C disc worked best on flat bedrock surfaces without deep cracks and crevices. While on a complex sea floor it was difficult to collect all sea urchins that were fastened in cracks and crevices or hiding under boulders. These findings are not surprising as sea urchins are difficult to remove even for divers using slim tools for manually collection (Christie pers. obs.). James and Siikavopio (2012) found a similar inability to capture fastened sea urchins on complex seafloor during a test of the SeaBedHarvester ROV in Båtsfjord, Norway, and Strand et al. (2020) found quicklime to be less efficient in killing urchins among boulders.

*C disc in the field*

Using a large vessel such as MAXTOR was not ideal. It may be better to operate from a smaller boat that is easier to manoeuvre and securely anchor to the sea floor regardless of wind or current situation. Alternatively, the C disc could be used from land if an area of high sea urchin density is identified in the proximity of roads and other infrastructure. Our diver also struggled with operating the C disc in the unusually strong currents. Selecting suitable areas and calm days with good weather and good visibility (needs daylight and low algal bloom) are important and will put a limitation on the C disc operation. In summary, users need to make sure that currents are low, assess the density of large sea urchins at the site and check the size and depth of the area. Based on this, a decision on whether to operate the C disc from a boat or from land should be made.

*Damage*

There was damage to the sea urchins at both sites (10 and 11 %). This is likely caused by a combination of things such as the two open round nozzles being hard (rounded steel edge) causing some of the sea urchins to be crushed as they are bumped into and suctioned. This was also indicated in the photos where several sea urchins and encrusting barnacles had been crushed and ripped off the rocks. When the catch was emptied from the collection bag, the bag needed to be turned upside down. Despite trying to empty it carefully the organisms were rolling around causing spines on sea urchins to be ripped off. Finally, as the C disc also collected some rocks, this may have caused additional damage to the sea urchins and bycatch in the catch bag.

*Bycatch*
There was a considerable amount of bycatch using the C disc (19 and 11 %). This is higher than for passive harvesting methods such as trapping (James and Siikavuopio 2014). But similar to other suction devices such as the SeaBedHarvester ROV which has a bycatch of 18 % (James and Siikavopio 2012). The advantage of the C disc is that the diver can see and to some degree avoid catching large organisms such as sea cucumbers. However, small organisms will be vulnerable. Despite there being a considerable bycatch, the majority of organisms were hard bodied with little visible damage. We cannot exclude that some small soft bodied organisms such as polychaetes and small crustaceans were also caught and damaged. For the occasional large sized bycatch such as sea cucumbers it is easy to quickly put them back into the ocean. Other bycatch organisms can be put back into the ocean while sorting the catch. Preferably they should be returned by spreading them over a larger area and not throwing them out together, whether this is feasible for future users of the C disc is outside the scope of this study.

*Short term impacts*
There were changes in abundance and coverage of organisms on the seafloor after using the C disc. Particularly large loose sitting organisms such as snails, hermit crabs, spider crabs and sea cucumbers were vulnerable to the C disc. Organisms tightly fastened to the sea floor such as barnacles, blue mussels and some algae were more likely to escape being captured by the C disc. Urchin barrens in northern-Norway, such as those surveyed in this trial, are typically hardbottom localities that are less diverse than other habitat types. Therefore, the risk of removing or damaging sensitive organisms or ecosystems in such habitats are low. Moreover, if the bycatch is placed back into the water in the area they were removed from, many organisms are likely to survive. The European organisation OSPAR (Oslo-Paris convention) has defined some habitats as "sensitive" to disturbance, including sponge grounds and coral gardens. Such habitats are not likely to be associated with barren grounds, but it will be important to survey the planned harvesting areas to classify habitat type prior to urchin removal. The effects of the C disc on other habitat types such as sand, mud and gravel may vary and is not investigated in this survey. A new targeted evaluation is required for these areas.
If the (added) goal of removing sea urchins is to restore kelp forests, the succession of organisms toward a kelp forest community will eventually alter the system towards higher diversity, even if some oose sitting organisms are permanently removed as there are few species associated with barren grounds. As kelp returns to an area, new species will eventually dominate and alter the system. Particularly mobile kelp fauna and fish predators will contribute to a higher complexity of food chains.

*C disc as a kelp recovery tool*
By removing sea urchins, the C disc was able to reduce sea urchins to a low number that would promote kelp recovery, depending on substrate type. Preferably a low density of ≤ 3 ind./m$^2$ allows for healthy regrowth of kelp (Verbeek et al. 2021). To completely remove sea urchins from areas with complex substrate type may require the use of additional tools such as baited traps that can attract the hiding urchins. While the C disc may harvest and remove sea urchins on only a limited area practical for operation within the time available for the diver, it may be questioned how large an area it is possible to clear, and to what price. The problem with urchin removal is that the area cleared is usually so small that neighbouring urchins quickly invade the area and graze the new kelp recruits. The efficiency and cost should be evaluated in terms of profit from the harvested urchins themselves, and if successful kelp recovery could be added as an additional result in the form of ecosystem service credits. It seems like the method has some of the same limitations on complex stony sea

bottom surfaces as quicklime, and the price for removal of a significantly large area must be evaluated concerning kelp recovery and maintaining the recovered kelp beds. The advantage of the C disc relative to quick lime is its ability to harvest sea urchins as a commercial resource. If the future strategy it to harvest sea urchins commercially while at the same time restore kelp forests, the C disc does not seem to be the most cost efficient and practical method. However, it may be considered in combination with other methods such as traditional trapping and diving.

*Recommendations for the C disc*

- Make the lip of the two open nozzles softer – adding short brushes or soft rubber edge.
- Make the opening of the brush nozzle angle more downward so that the suction don't dissipate and make the brushes shorter for more gentle removal of green sea urchins.

# 5 Conclusion

The C disc had a slightly higher catch efficiency compared to other traditional tools while at the same time reducing the urchins to a level that could potentially promote kelp recovery, at least on smoother hardbottom surfaces. However, there was a higher level of damage to the sea urchins than observed with traditional harvesting methods such as traps and divers. This will be an important consideration for future commercial users. Because the large boat used in the current survey had to be repositioned several times, the diver struggled to hold the C disc in the strong currents and the CPUE varied based on density of sea urchins and bottom type; the authors suggest properly surveying several areas prior to operation in order to choose the best area and methods. The bycatch reflected the local community and the effects on the seafloor was most notable on loose sitting organisms. Given the low biological diversity at barren grounds in northern-Norway and the low damage to bycatch organisms it is likely that most organisms will survive if returned quickly to the sea at the site they were caught. However, the bycatch will need to be sorted from the catch, adding to both the cost and time when using device and needs to be considered by future users.
If the future strategy it to harvest sea urchins commercially while at the same time restore kelp forests, the C disc does not seem to be the most cost efficient and practical method. However, it may be considered in combination with other methods such as traditional trapping and diving. A challenge is to develop an efficient and profitable method for sea urchin harvest that can result in kelp restoration on both short time and long-time perspectives. The C disc does not seem to be the most cost-efficient method for achieving such combined goals but can be evaluated as part of a multi-method strategy.

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# Appendix

Appendix table 1. Number of individuals (ind/m2) in photo frames before and after C disc use at site 1, Ytre Kårvika.

| Species | Tansect nr. | Frame nr. | Nr. before | ind/m2 before | Nr. after | ind/m2 after |
|---|---|---|---|---|---|---|
| Sea urchins | 1 | 1 | 27 | 54 | 10 | 20 |
| Sea urchins | 1 | 2 | 8 | 16 | 6 | 12 |
| Sea urchins | 1 | 3 | 13 | 26 | 21 | 42 |
| Sea urchins | 1 | 4 | 9 | 18 | NA | NA |
| Sea urchins | 1 | 5 | 13 | 26 | NA | NA |
| Sea urchins | 2 | 1 | 11 | 22 | 0 | 0 |
| Sea urchins | 2 | 2 | 10 | 20 | 3 | 6 |
| Sea urchins | 2 | 3 | 21 | 42 | 0 | 0 |
| Sea urchins | 2 | 4 | 11 | 22 | NA | NA |
| Sea urchins | 2 | 5 | 11 | 22 | NA | NA |
| Sea urchins | 3 | 1 | 20 | 40 | 1 | 2 |
| Sea urchins | 3 | 2 | 25 | 50 | 5 | 10 |
| Sea urchins | 3 | 3 | 28 | 56 | 1 | 2 |
| Sea urchins | 3 | 4 | 34 | 68 | NA | NA |
| Sea urchins | 3 | 5 | 43 | 86 | NA | NA |
| Average | | | | 37,86667 | | 10,44444 |
| Total | | | | 568 | | 80 |
| Snail/hermit crab | 1 | 1 | 9 | 18 | 4 | 8 |
| Snail/hermit crab | 1 | 2 | 10 | 20 | 4 | 8 |
| Snail/hermit crab | 1 | 3 | 3 | 6 | 6 | 12 |
| Snail/hermit crab | 1 | 4 | 1 | 2 | NA | NA |
| Snail/hermit crab | 1 | 5 | 8 | 16 | NA | NA |
| Snail/hermit crab | 2 | 1 | 8 | 16 | 10 | 20 |
| Snail/hermit crab | 2 | 2 | 14 | 28 | 21 | 42 |
| Snail/hermit crab | 2 | 3 | 24 | 48 | 19 | 38 |
| Snail/hermit crab | 2 | 4 | 22 | 44 | NA | NA |
| Snail/hermit crab | 2 | 5 | 27 | 54 | NA | NA |

| | | | | | | |
|---|---|---|---|---|---|---|
| Snail/hermit crab | 3 | 1 | 42 | 84 | 19 | 38 |
| Snail/hermit crab | 3 | 2 | 10 | 20 | 3 | 6 |
| Snail/hermit crab | 3 | 3 | 3 | 6 | 7 | 14 |
| Snail/hermit crab | 3 | 4 | 11 | 22 | NA | NA |
| Snail/hermit crab | 3 | 5 | 4 | 8 | NA | NA |
| Average | | | | 26,13333 | | 20,66667 |
| Total | | | | 392 | | 128 |
| Sea cucumber | 1 | 4 | 1 | 2 | | |
| Sea cucumber | 3 | 3 | 1 | 2 | | |
| Red sea urchin | 1 | 5 | 1 | 2 | | |
| Blue mussel | 3 | 1 | 0 | 0 | 5 | 10 |
| Buccinum sp. | 3 | 3 | 1 | 2 | | |
| Sea star | 3 | 3 | 1 | 2 | | |
| Whelk | 2 | 2 | 1 | 2 | | |
| Average | | | | 1,714286 | | 10 |
| Total | | | | 12 | | 10 |
| Red algae | 1 | 1 | 7 | 14 | 1 | 2 |
| Red algae | 1 | 2 | 17 | 34 | 3 | 6 |
| Red algae | 1 | 3 | 7 | 14 | 0 | 0 |
| Red algae | 1 | 4 | 9 | 18 | NA | NA |
| Red algae | 1 | 5 | 7 | 14 | NA | NA |
| Red algae | 2 | 1 | 0 | 0 | 0 | 0 |
| Red algae | 2 | 2 | 1 | 2 | 0 | 0 |
| Red algae | 2 | 3 | 6 | 12 | 1 | 2 |
| Red algae | 2 | 4 | 0 | 0 | NA | NA |
| Red algae | 2 | 5 | 0 | 0 | NA | NA |
| Red algae | 3 | 1 | 3 | 6 | 20 | 40 |
| Red algae | 3 | 3 | 20 | 40 | 5 | 10 |
| Average | | | 6,416667 | 12,83333 | 3,75 | 7,5 |
| Total | | | | 154 | | 60 |

Appendix table 2. Percent (%) coverage of encrusting or dense organisms in photo frames before and after C disc use at site 1, Ytre Kårvka.

| **Species** | **Tansect nr.** | **Frame nr.** | **Percent before (%)** | **Percent after (%)** |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Encrusting algae | 1 | 1 | 50 | 50 |
| Encrusting algae | 1 | 2 | 50 | 50 |
| Encrusting algae | 1 | 3 | 40 | 40 |
| Encrusting algae | 1 | 4 | 25 | 25 |
| Encrusting algae | 1 | 5 | 20 | 20 |
| Encrusting algae | 1 | 6 | 40 | 30 |
| Encrusting algae | 1 | 7 | 40 | 40 |
| Encrusting algae | 1 | 8 | 50 | 45 |
| Encrusting algae | 1 | 9 | 30 | 20 |
| Average | | | 38,3 | 35,6 |
| Green algae | 1 | 1 | 20 | 0 |
| Green algae | 1 | 2 | 15 | 0 |
| Green algae | 1 | 3 | 10 | 10 |
| Green algae | 1 | 6 | 5 | 5 |
| Green algae | 1 | 7 | 25 | 0 |
| Green algae | 1 | 8 | 5 | 5 |
| Average | | | 13,3 | 3,3 |

Appendix table 3. Number of individuals (ind/m2) in video transects before and after C disc use at site 1, Ytre Kårvika.

| **Species** | **Tansect nr.** | **Meter nr.** | **Nr. before** | **Nr. after** |
|---|---|---|---|---|
| Sea urchins | 1 | 1 | 101 | 4 |
| Sea urchins | 1 | 2 | 109 | 12 |
| Sea urchins | 1 | 3 | 82 | 12 |
| Sea urchins | 1 | 4 | 60 | 12 |
| Sea urchins | 1 | 5 | 87 | 13 |
| Sea urchins | 1 | 6 | 79 | 14 |
| Sea urchins | 1 | 7 | 38 | 16 |
| Sea urchins | 1 | 8 | 98 | 13 |
| Sea urchins | 1 | 9 | 38 | 2 |
| Average | | | 76,9 | 10,9 |
| Total | | | 692 | 98 |
| Gibbula/Pagurus | 1 | 1 | 62 | 24 |
| Gibbula/Pagurus | 1 | 2 | 48 | 36 |
| Gibbula/Pagurus | 1 | 3 | 53 | 11 |
| Gibbula/Pagurus | 1 | 4 | 35 | 5 |
| Gibbula/Pagurus | 1 | 5 | 33 | 26 |
| Gibbula/Pagurus | 1 | 6 | 17 | 14 |
| Gibbula/Pagurus | 1 | 7 | 11 | 14 |
| Gibbula/Pagurus | 1 | 8 | 27 | 10 |
| Gibbula/Pagurus | 1 | 9 | 25 | 3 |
| Average | | | 34,6 | 15,9 |
| Total | | | 311 | 143 |

| | | | | |
|---|---|---|---|---|
| Sea cucumber | 1 | 2 | 3 | 0 |
| Sea cucumber | 1 | 3 | 2 | 0 |
| Sea cucumber | 1 | 4 | 2 | 0 |
| Sea cucumber | 1 | 6 | 1 | 0 |
| Average | | | 2 | 0 |
| Total | | | 8 | 0 |
| Blue mussel | 1 | 7 | 8 | 8 |
| Blue mussel | 1 | 8 | 1 | 0 |
| Blue mussel | 1 | 1 | 4 | 1 |
| Average | | | 4,333333 | 3 |
| Total | | | 13 | 9 |

Appendix table 4. Percent (%) coverage of encrusting or dense organisms in video transects before and after C disc use at site 1, Ytre Kårvika.

| **Species** | **Tansect nr.** | **Frame nr.** | **Percent before (%)** | **Percent after (%)** |
|---|---|---|---|---|
| Encrusting algae | 1 | 1 | 60 | 60 |
| Encrusting algae | 1 | 2 | 60 | 40 |
| Encrusting algae | 1 | 3 | 30 | 50 |
| Encrusting algae | 1 | 4 | 40 | NA |
| Encrusting algae | 1 | 5 | 30 | NA |
| Encrusting algae | 2 | 1 | 10 | 5 |
| Encrusting algae | 2 | 2 | 10 | 5 |
| Encrusting algae | 2 | 3 | 14 | 10 |
| Encrusting algae | 2 | 4 | 5 | NA |
| Encrusting algae | 2 | 5 | 5,0 | NA |
| Encrusting algae | 3 | 1 | 40 | 30 |
| Encrusting algae | 3 | 2 | 60 | 30 |
| Encrusting algae | 3 | 3 | 40 | 50 |
| Encrusting algae | 3 | 4 | 35 | NA |
| Encrusting algae | 3 | 5 | 40 | NA |
| Average | | | 31,9 | 31,1 |

Appendix table 5. Number of individuals (ind/m2) in photo frames before and after C disc use at site 2, Berg.

| **Species** | **Tansect nr.** | **Frame nr.** | **Nr. before** | **ind/m2 before** | **Nr. after** | **ind/m2 after** |
|---|---|---|---|---|---|---|
| Sea urchins | 1 | 1 | 15 | 30 | 0 | 0 |
| Sea urchins | 1 | 2 | 5 | 10 | 0 | 0 |
| Sea urchins | 1 | 3 | 15 | 30 | 0 | 0 |
| Sea urchins | 1 | 4 | 2 | 4 | 0 | 0 |
| Sea urchins | 1 | 5 | 8 | 16 | 0 | 0 |
| Sea urchins | 2 | 1 | 17 | 34 | 0 | 0 |
| Sea urchins | 2 | 2 | 9 | 18 | 0 | 0 |
| Sea urchins | 2 | 3 | 24 | 48 | 1 | 2 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Sea urchins | 2 | 4 | 25 | 50 | 2 | 4 |
| Sea urchins | 2 | 5 | 14 | 28 | 0 | 0 |
| Average | | | | 26,8 | | 0,6 |
| Total | | | | 268 | | 6 |
| Snail/hermit crab | 2 | 2 | 3 | 6 | 6 | 12 |
| Snail/hermit crab | 2 | 5 | 1 | 2 | 0 | 0 |
| Snail/hermit crab | 1 | 4 | 1 | 2 | 4 | 8 |
| Snail/hermit crab | 1 | 5 | 2 | 4 | 0 | 0 |
| Average | | | | 3,5 | | 5 |
| Total | | | | 14 | | 20 |
| Chiton (Mollusca) | 1 | 2 | 1 | 2 | 0 | 0 |
| Common whelk | 1 | 2 | 1 | 2 | 0 | 0 |
| *Patella* | 1 | 5 | 2 | 4 | 14 | 28 |
| Unknown clam | 2 | 1 | 1 | 2 | 0 | 0 |
| Unknown clam | 2 | 4 | 1 | 2 | 0 | 0 |
| Unknown clam | 2 | 5 | 1 | 2 | 3 | 6 |
| Sea star | 2 | 5 | 1 | 2 | 0 | 0 |
| Chiton (Mollusca) | 2 | 1 | 0 | 0 | 1 | 2 |
| Sea star | 2 | 2 | 0 | 0 | 2 | 4 |
| Average | | | | 1 | | 3 |
| Total | | | | 4 | | 12 |

Appendix table 6. Percent (%) coverage of encrusting or dense organisms in photo frames before and after C disc use at site 2, Berg.

| **Species** | **Tansect nr.** | **Frame nr.** | **Percent before (%)** | **Percent after (%)** |
|---|---|---|---|---|
| Green algae | 1 | 1 | 45 | 30 |
| Green algae | 1 | 2 | 10 | 10 |
| Green algae | 1 | 3 | 10 | 15 |
| Green algae | 1 | 4 | 10 | 20 |
| Green algae | 1 | 5 | 0 | 30 |
| Green algae | 2 | 1 | 0 | 2 |
| Green algae | 2 | 2 | 50 | 0 |
| Green algae | 2 | 3 | 5 | 15 |
| Green algae | 2 | 4 | 25 | 30 |
| Green algae | 2 | 5 | 0 | 5 |
| Average | | | 15,5 | 15,7 |
| Total | | | 155 | 157 |
| Blue mussel | 1 | 1 | 1 | 80 |
| Blue mussel | 1 | 2 | 80 | 80 |
| Blue mussel | 1 | 3 | 20 | 15 |
| Blue mussel | 1 | 4 | 80 | 20 |
| Blue mussel | 1 | 5 | 30 | 20 |
| Blue mussel | 2 | 1 | 1 | 0 |

| | | | | |
|---|---|---|---|---|
| Blue mussel | 2 | 2 | 45 | 40 |
| Blue mussel | 2 | 3 | 35 | 45 |
| Blue mussel | 2 | 4 | 70 | 60 |
| Blue mussel | 2 | 5 | 80 | 70 |
| Average | | | 44,2 | 43 |
| Total | | | 442 | 430 |
| Barnacles | 1 | 1 | 90 | 80 |
| Barnacles | 1 | 2 | 80 | 80 |
| Barnacles | 1 | 3 | 80 | 15 |
| Barnacles | 1 | 4 | 80 | 20 |
| Barnacles | 1 | 5 | 30 | 20 |
| Barnacles | 2 | 1 | 5 | 0 |
| Barnacles | 2 | 2 | 0 | 5 |
| Barnacles | 2 | 3 | 10 | 10 |
| Barnacles | 2 | 4 | 10 | 10 |
| Barnacles | 2 | 5 | 5 | 0 |
| Average | | | 39 | 24 |
| Total | | | 390 | 240 |

Appendix table 7. Number of individuals (ind/m2) in video transects before and after C disc use at site 2, Berg.

| **Species** | **Tansect nr.** | **Meter nr.** | **Nr. before** | **Nr. after** |
|---|---|---|---|---|
| Sea urchins | 1 | 1 | 13 | 6 |
| Sea urchins | 1 | 2 | 27 | 10 |
| Sea urchins | 1 | 3 | 28 | 8 |
| Sea urchins | 1 | 4 | 20 | 4 |
| Sea urchins | 1 | 5 | 21 | 1 |
| Sea urchins | 1 | 6 | 41 | 3 |
| Sea urchins | 1 | 7 | 24 | 2 |
| Sea urchins | 1 | 8 | 9 | 0 |
| Sea urchins | 1 | 9 | 7 | 0 |
| Sea urchins | 2 | 1 | 46 | 4 |
| Sea urchins | 2 | 2 | 25 | 9 |
| Sea urchins | 2 | 3 | 39 | 8 |
| Sea urchins | 2 | 4 | 44 | 10 |
| Sea urchins | 2 | 5 | 29 | 0 |
| Sea urchins | 2 | 6 | 20 | 10 |
| Sea urchins | 2 | 7 | 30 | 4 |
| Sea urchins | 2 | 8 | 25 | 0 |
| Average | | | 26,35294 | 4,647059 |
| Total | | | 448 | 79 |

Appendix table 8. Percent (%) coverage of encrusting or dense organisms in video transects before and after C disc use at site 2, Berg.

| Species | Tansect nr. | Meter nr. | Percent before (%) | Percent after (%) |
|---|---|---|---|---|
| 1 | 1 | Algae | 60 | 30 |
| 1 | 2 | Algae | 20 | 10 |
| 1 | 3 | Algae | 20 | 15 |
| 1 | 4 | Algae | 35 | 20 |
| 1 | 5 | Algae | 30 | 30 |
| 1 | 6 | Algae | 5 | 5 |
| 1 | 7 | Algae | 10 | 8 |
| 1 | 8 | Algae | 15 | |
| 1 | 9 | Algae | 0 | 0 |
| Average | | | 21,66667 | 14,75 |
| 1 | 1 | Blue mussel | 60 | 60 |
| 1 | 2 | Blue mussel | 80 | 80 |
| 1 | 3 | Blue mussel | 80 | 80 |
| 1 | 4 | Blue mussel | 70 | |
| 1 | 5 | Blue mussel | 50 | 45 |
| 1 | 6 | Blue mussel | 15 | 15 |
| 1 | 7 | Blue mussel | 0 | 0 |
| 1 | 8 | Blue mussel | 10 | 10 |
| 1 | 9 | Blue mussel | 0 | 0 |
| Average | | | 40,55556 | 36,25 |
| 1 | 1 | Barnacles | 40 | 40 |
| 1 | 2 | Barnacles | 40 | 40 |
| 1 | 3 | Barnacles | 40 | 40 |
| 1 | 4 | Barnacles | 35 | 35 |
| 1 | 5 | Barnacles | 50 | 50 |
| 1 | 6 | Barnacles | 35 | 35 |
| 1 | 7 | Barnacles | 35 | 35 |
| 1 | 8 | Barnacles | 35 | 35 |
| 1 | 9 | Barnacles | 20 | 20 |
| Average | | | 36,66667 | 36,66667 |
| 2 | 1 | Algae | 0 | 0 |
| 2 | 2 | Algae | 0 | 0 |
| 2 | 3 | Algae | 20 | 15 |
| 2 | 4 | Algae | 25 | 20 |
| 2 | 5 | Algae | 40 | 40 |
| 2 | 6 | Algae | 75 | 60 |
| 2 | 7 | Algae | 80 | 70 |
| 2 | 8 | Algae | 50 | 50 |
| 2 | 9 | Algae | 0 | 0 |
| Average | | | 32,22222 | 28,33333 |
| 2 | 1 | Blue mussel | 0 | 0 |
| 2 | 2 | Blue mussel | 30 | 30 |
| 2 | 3 | Blue mussel | 23 | 20 |

| | | | | |
|---|---|---|---|---|
| 2 | 4 | Blue mussel | 10 | 10 |
| 2 | 5 | Blue mussel | 40 | 40 |
| 2 | 6 | Blue mussel | 40 | 35 |
| 2 | 7 | Blue mussel | 70 | 70 |
| 2 | 8 | Blue mussel | 60 | 60 |
| 2 | 9 | Blue mussel | 15 | 15 |
| Average | | | 32 | 31,11111 |
| 2 | 1 | Barnacles | 10 | 10 |
| 2 | 2 | Barnacles | 20 | 15 |
| 2 | 3 | Barnacles | 40 | 40 |
| 2 | 4 | Barnacles | 50 | 50 |
| 2 | 5 | Barnacles | 70 | 70 |
| 2 | 6 | Barnacles | 70 | 70 |
| 2 | 7 | Barnacles | 20 | 20 |
| 2 | 8 | Barnacles | 30 | 25 |
| 2 | 9 | Barnacles | 0 | 0 |
| Average | | | 34,44444 | 33,33333 |

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