Project information

Project title

Sea urchin harvest: ecosystem recovery, integrated management of social-ecological system, ecosystem service and sustainability (ECOURCHIN)

Year

2016

Project leader

Wenting Chen and Hartvig Christie

Geographical localization of the research project in decimal degrees (max 5 per project, ex. 70,662°N and 23,707°E)

65°70′N to 70°70′N along the Norwegian Coast

Participants

Norwegian Institute for Water Research (NIVA): Wenting Chen, Hartvig Christie, Hege Gundersen, Eli Rinde, Trine Bekkeby

The Arctic University of Norway (UiT): Claire Armstrong, Godwin K. Vondolia

NOFIMA: Philip James

University of California Berkeley : Peter Berck

Associated partner from Industry who newly joined in May this year: KASTON International: Brain Takeda

Flagship

MIKON

Funding Source

MIKON - research theme 3: "Impacts of industrial development on ecosystem services and social-ecological systems in the North".

Summary of Results

Results

Summary of Results

Extensive work has been carried out in each WP in 2016 based on the work done in 2015 where we qualitatively studied environmental impacts of urchin harvesting and the relevant ecosystem services, reviewed the field work on urchin kelp population dynamics and studied the basic idea for urchin harvest bioeconomic model.

-WP1: Where to harvest?

We constructed both basedline spatial distribution of kelp along the three northern counties in Norway, i.e. Nordland, Troms and Finnmark. A GIS programming tool is used to cover a gradient of different depths in addition to (and disentangled from) distances to kelp forest, which enables us to compile all the relevant dataset. The GIS programming makes use of information on relevant existing mapping layers including geophysical modelling data of depth, wave- and current exposure, sea bed terrain.

In the first round we mapped the existing area with kelp forest (Laminaria hyperborea) which is now located in coastal areas with relatively high wave exposure. This is due to green sea urchins (Strongylocentrotus droebachiensis) are susceptible to strong waves so that they are not able to grow in the area with high wave exposure (Fagerli et., 2015).

In the second round, we predict the areas where both Laminaria Hyperborea and Saccharina Latissma will be recovered. Different from Gundersen et al (2011), the predicted area only covers the depth no more than 30 m. This is the depth where sea urchins will populate along the edge of the kelp forest. Therefor we approximate the future baseline distribution of urchin population along the kelp forest. As scuba divers will not go deeper than 20m for urchin harvesting and dredging is commonly used for example in Iceland for urchin harvesting at a depth more than 20m. We thus look at two scenarios of harvesting technics, the scuba diving and the dredging. The baseline distribution of urchin population is also mapped according to the two different harvest techniques.

The basedline distribution for sea urchins and kelp forest (both Laminaria Hyperborea and Saccharina Latissma) are mapped at community level. All the 83 communities in the three northern counties are covered. We do not present the maps for all the 83 community here

Figure 1 shows an example from Skrova. The dark blue area shows the existing Laminaria Hyperborea. The light blue area indicates the future area with the recovered Laminaria Hyperborea after the removal or harvesting of the small sea urchins. The red area indicates the future area with the recovered Saccharina Latissma after the urchin removal. The light yellow area marks the region with the depth between 0-20 m. This is the area that divers could reach by using scuba diving technique when harvesting sea urchins. The deeper yellow marks the area with depth between 20 m and 30 m where dredging technique can be used for urchin harvesting.

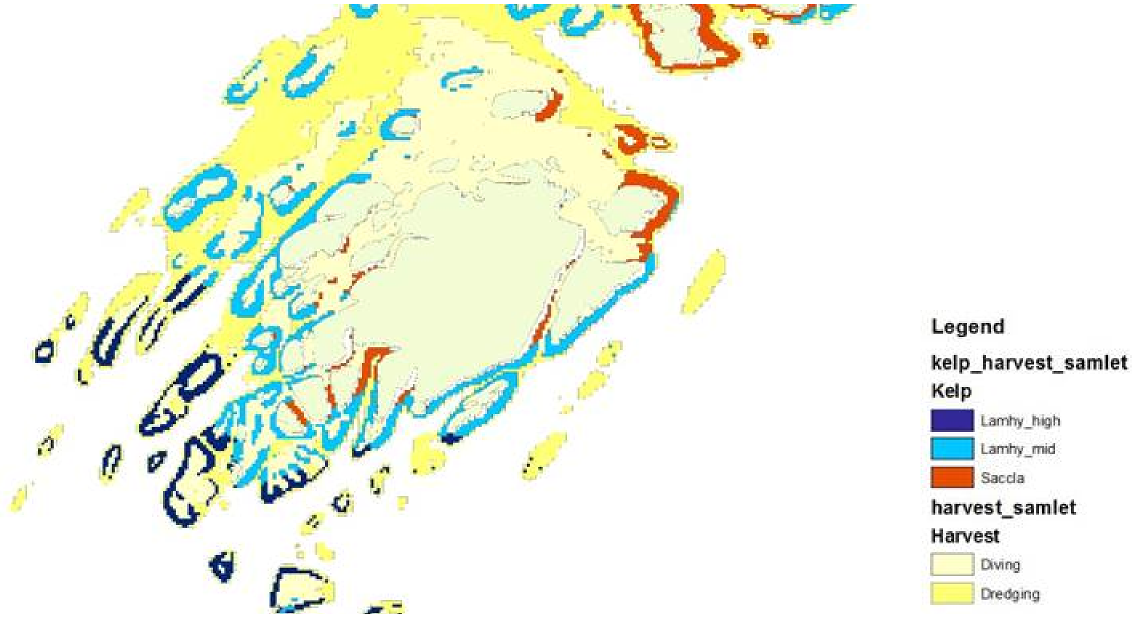

Figure 1: Baseline kelp recovery and urchin distribution along the recovered kelp belt.

-WP2: Impact of harvest on ecosystem and how to harvest?

Impact of harvest on ecosystem

Several potential impacts were identified in 2015, i.e. food production service (cod and other commercial fishery), cultural regulation service (diving, recreational fishery), and carbon regulation service (carbon storage in the kelp biomass), other services like wave damping, water cleaning.

In 2015 we do find that urchin density, size, and roe quality vary with distance to kelp. The green sea urchin aggregate, and the largest individuals (test diameter about 50-60 mm) can aggregate in densities between 50 and 100 per m2 close to kelp vegetation. Data from Vega show that sea urchins grow faster and develop larger gonads close to kelp. Resent unpublished results from Porsanger (Finnmark) revealed 5 times higher gonad weight close to kelp than far from kelp vegetation. Gonad index vary with season, but in autumn, sea urchins close to kelp vegetation may reach size and gonad index ready for marked quality.

In 2016 we further deepened the knowledge on the potential impacts by analyizing the data collected via “Sea urchin-kelp” project in Flagship “Fjord and coast” in 2015. We find out the increase in development of invertebrates and fish in the recovered kelp beds. In kelp recovery area, we found the ecosystem services have the following characteristics.

-Significant increase in biodiversity (Figure 2)

- Habitats for juvenile codfish and potentially increase in coastal cod fish stock. (Figure 3)

- Improved nutrient and habitat conditions for commercial fish and crabs

- CO_2 storage

-Increase in gonad production in the remaining sea urchins.

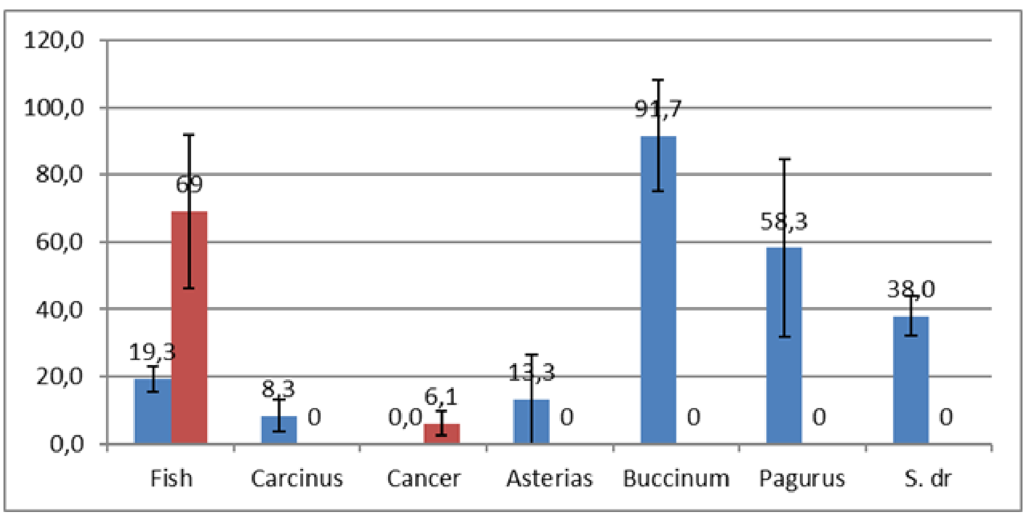

Figure 2: Biodiversity in recovered kelp beds vs sea urchin barren grounds, (number of species average per station),Vega 2015 (Christie, 2016)

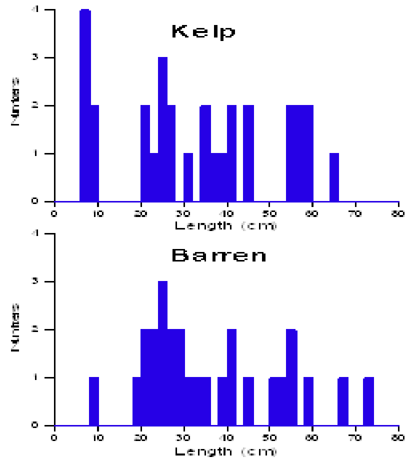

Figure 3: Numbers of coastal cod in kelp forest and Barren grounds respectively at different length.

How to harvest

In 2015, we a very primative bioeconomic model to quantify how much economic value of urchin harvesting will be over the years under the harvesting scenario "repeated harvest of sea urchins on barren grounds”. It is a social planner model for harvesting urchins on the barrens.. As no cost data on urchin farming and harvesting available this year, we only calculated the gross revenue of the urchin harvesting when harvest is done from barrens. Our result shows that the maximum sustainable yields could be up to 0.81 mill tonne per year if we do not consider harvesting capacity constraints. With the current harvesting capacity constraints, the maximum harvesting is estimated to be 0.5 mill tonne per year. If we assume the wet raw urchins are sold at a fixed market price at 48 NOK/kg before farming, the gross annual revenue without considering harvesting costs will be 39000 million NOK per year.

In 2016, we deepened our analysis by looking at the second harvesting scenario “Harvesting the big sea urchins along the recovered kelp forest”. We first looked at different techniques of harvesting. And then the data on cost of harvesting are collected. Secondly, a bioeconomic model for “harvesting along the recovered kelp forest” is constructed and programed. Market price data on wild and farmed urchins are further improved in greater details. Urchin and kelp population growth data are collected. The model is proogrammed by using R. In the model we assume the kelp forest is already recovered and we develop optimal harvesting strategy between the two. Relevant data are all collected. We will provide the optimal harvesting path by the end of this year.

Here we provide the description of collection techniques and some examples on cost data.

Collection techniques:

Dredging: If a dredge is used then fishing activities could be in relatively deep water (10-50m depth) depending on the area, bottom topography, currents and tides and the presence/absence of urchins. For urchins to be present at depths greater than 20-30m then drift seaweed must be available as a food source which requires a particular combination of physical and environmental conditions. These are normally quite restrictive but when they occur, they are quite productive (for example most of the 120tonne of sea urchins fished in Iceland come from a relatively small area at depths of 20-30m. The area experiences very strong currents and the urchins are feeding primarily feeding on drift seaweed that is swept into the area). Dredging could happen up to 0.5km from shore or even further if the conditions suit. For example relatively shallow (< 50m depth) and a smooth flat seafloor.

(Note: min10m . Iceland 30m)

SCUBA Diving: Diving activities to harvest sea urchins normally occur within 0-50m of the coastline. However, this is also very dependent on the conditions at each individual collection site. Normally diving activities are restricted to depths less than 20m. Diving to greater depths can be done but requires very experienced technical divers.

(5-10m Kavia)

Trapping: Harvesting sea urchins with traps is not restricted by depth but by the bottom topography, local conditions (currents and tides) and the presence/absence of urchins. This activity could occur anywhere between 5m to 100m depth and 5-500m from shore.

(Currents limit and wave limit, low wave exposure, 1m- max 50 min)

Additional fishing effort:

All of these techniques require effort into finding new areas of sea urchins. On average for every 2-3 days fishing it will take 1 day of looking for new fishing areas (a month fishing requires 3-4 days of investigative diving)

Collection areas covered by different collection techniques:

Dredging could cover areas of between 0,5-1km^2/day ((newest NOFIRMA report, Iceland))

SCUBA diving could cover areas of between 50-200m^2/day (Phil's estimate)

Trapping would cover much smaller areas in terms of actual harvesting but traps could be set over an area between 10m^2/trap/day. (Phil's estimate, trap dependent , (number of trap, size and type of the trap))

Set costs (NOK):

Testing and compliance: *Approx.* 10-15,000/year

Insurance: *Approx.* 15,000

Petrol: *Approx.* 60,000

Maintenance (Boat): *Approx.* 10,000

Freight: Depends on quantities harvested and transported but makes up approximately 50% of the set costs

Labor costs (diving):

Hire diver: 30-40,000 NOK/month one diver 1-5 days, 8 hour day (approximately 2 dives/day)

Personnel: If an owner/operator of the company is also a diver these costs come under permanent staff costs (1 FTE / approximately 550,000 + company tax)

Start-up Investment cost:

Boat: (Approximately 0,5-1million)

Diving equipment: (an estimate would be 2-300,000 including a compressor)

Dredge equipment: (an estimate would be 2-300,000)

-WP3: Impact on communities and ecosystem services

In 2015 we qualitatively identified the potential ecosystem services that may be benefited from urchin harvesting industry, e.g. carbon regulation services, food production services and cultural services (tourism). In 2016 we quantified two of the services that is carbon regulation services and the coastal cod fishery from kelp forest recovery.

Carbon regulation services

Kelp forest is playing an important role in binds CO_2 in the ocean. Kelp breaks up partly due to abrasion partly due to the plants shed leaves each year (Christie et al 2003). Some of the shed leaves are consumed by secondary producers (Fredriksen 2003, Norderhaug et al 2003) and some is broken down by microbes (Hedges and Keil 1995). The United Nations Framework Convention on Climate Change (1992) defines a "Sink" as "any process, activity or mechanism which removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas from the atmosphere." The Convention recognized the importance of oceans, coastal and marine ecosystems in sinking and being a reservoir of the global greenhouse gas (GHGs). Similar to the terrestrial ecosystems, coastal and marine ecosystems could mitigate climate change by removing GHGs from the atmosphere leading to an accumulation of carbon stocks. In analog to an important feature of Land Use, Land-Use Change and Forestry (LULUCF) activities (UN, 1992), the GHGs mitigation by coastal and marine ecosystems is also potential reversible and thus non-permanence of the accumulated carbon stocks.

From previous studies we know that kelp forest biomass varies with habitat, from under 10 kg per m^2 up to 50 kg per m^2, depending on exposure to waves and currents, depth and latitude (Cain 1971, Sjøtun et al 2006). In the calculations presented here, we begin with a conservative average value of 10 kg fresh weight kelp per m^2 from 0-20 m deep. 10 kg of fresh kelp will have a dry weight of about 3 kg, and about 1/3 (ie. 1 kg) of this is carbon. Carbon has an atomic weight of 12 and oxygen 16, so that the molecular weight of CO_2 is 44. One square metre of kelp forest bottom will therefore bind 3.6 kg CO_2 (1kg x 44/12).

For the current estimation , we only look at the potential recovery of Saccharina Latissma. A hotspot for kelp recovery is indentified in Northern Norway between 65 N and 70 N. The storage of carbon in the kelp biomass could be amount to 4 Million ton. When translated into social cost of carbon, with the US estimation the total social benefits of carbon stored in the recovered Saccharina Latissma will be amount to 1000 Million NOK if 5% social discount rate is used.

Coastal cod fishery from kelp forest recovery

The ecosystem-based fisheries management proposes a broader scope for fisheries management in order to address the effects of fishing on the marine ecosystems including diversity for sustainable management of fisheries (Pope and Syme, 2006). It is in this regard that fisheries policies have started to take the effects of harvests on marine habitats into account e.g. the Magnusson-Stevens Fishery Conservation and Management Act. In addition, the ecosystem-based management requires policies to take explicit account of the interconnectedness within systems with recognition of the importance of interactions between target and non-target species (McLeod et al., 20015). This part of the project presents another variant of bioeconomic model of habitat-fisheries interactions for kelp forest and the coastal cod fisheries in Norway. Specifically, the bioeconomic model considers the case in which kelp forest serves a habitat for coastal cod but at the same time, standing kelp forests provide other supporting ecosystem services such as carbon storage. This builds on the bioeconomic model presented in Kahui et al. (2016) but makes two important contributions. First, the habitat (i.e. kelp forest) in the present model has a commercial value whereas cold-water coral (CWC) in Kahui et al. (2016) does not have commercial value. Secondly, kelp forest is a renewable natural resource whereas CWC was modelled as non-renewable resource due to its slow growth.

Kelps (Laminaria hyperborea) have long been known for providing habitats for different fish species since 1834 when Darwin observed aggregation of fish on kelp forests during a trip to South America (Gundersen et al., 2016). Kelp forests in shallow coastal communities allow for high nutrient uptake, photosynthesis and growth, and these foster an extraordinary diversity of species and interactions within these communities (Tegner and Dayton, 2000). A recent review of potential effects of kelp species on local fisheries is Bertocci et al. (2015). This review of kelp-fishery interactions identify that kelp forests are associated with four fish traits of adult abundance, early stage abundance, diversity and feeding. Thus, kelp forests provide essential habitat for adult fish and juvenile (Bertocci et al., 2015). Furthermore, Bodvin et al. (2015) analyze the effects of kelp harvesting on near-shore fish and crab abundance in Nord-Trøndelag in Norway. The results indicate that there was a significant reduction in small cod caught but an increased amount of wrasse caught on the harvested field two years after kelp harvesting, compared to pre-harvesting catches. This indicates conflicting effects of kelp harvesting on these species. Michaelsen (2012) also finds that juvenile cod was associated with macroalgae habitats based on studies conducted in Porsabgerfjord and Ullfjord in Norway.

In addition to the provision of essential habitat for coastal fish species, kelp forests have been recognized for many multiple economic uses (see e.g. Gundersen et al., 2016). For instance, several products can be derived from kelp alginate. In addition, kelp has a potential for biofuels, feed for aquaculture and livestock, alginate processing and is has led to an increasing interest in large scale harvesting and cultivation of kelp in Norway (Gundersen et al., 2016). Standing kelp forests are known to store carbon and recent estimations of carbon content of kelp forests in UK show that this ecosystem property may have previously been undervalued (Smale et al., 2016). Carbon content was estimated to be about 30% of dry weight of kelp (Smale et al., 2016). The average conversion factor of 22.6% between FW (fresh weight) and DW (dry weight). Specifically, Smale et al. (2016) estimate that site-level averages of total standing stock of carbon ranged from 251 g C m-2 to 1820 g C m-2. The study-wide average for carbon contained within kelp forests was 721 ± 140 g C m-2, of which about 86% stored in the canopy forming rather than sub-canopy, plants.

Regulations for kelp-fishery management in Norway:

According to Vea and Ask (2011), the management of kelp-fishery interactions in Norway undergone three regulations. Firstly, based on Seawater Fisheries Act, a four-year cycle management for kelp forests was designed to ensure kelp forest regrowth with minimum conflicts with fishing activities (Svendsen, 1972). The four-year cycle was later increased to a five-year cycle to take into account new findings that kelp grows faster (Sjøtun, 2000). Secondly, the Continental Shelf Act was recognized to guide harvesting of seaweed in 1994. In this direction, the Ministry of Fisheries appointed a committee made up of The Directorate of Fisheries, The Directorate of Nature Management, The Institute of Marine Research, The Norwegian Institute for Nature Research, and The Norwegian Fishermen's Association. The work of this committee resulted in Seaweed Management Plan, which is based on the knowledge of the Norwegian seaweed ecology, harvesting and management. Thirdly, from 2009, seaweed resources management was included in a new act together with fisheries: The Marine Resources Act. The purpose of this act, as noted by Vea and Ask (2011), is to "ensure sustainable and economically profitable management of wild living marine resources and to promote employment and settlement in coastal communities".

We have constructed a bioeconomic model to study how increase in kelp forest habitat will contribute to the coastal cod fishery. The model is based on Foley et al (2012) and Kahui et al (2016). We are in the progress of collecting all the data and simulation will be done in the end of year 2016.

For the Management

Sea urchin harvesting industry is still at the cradle stage in Norway. While in the past two years, urchin harvesting has caught more and more attention in the research world (e.g. EU project: ResUrch and the Northern Peripheries and Arctic pre-project (Sea urchin fishing in the European Northern Periphery Area). Long coast line with abundant sea urchin population in the North and the high demand in the international market provide a unique potential for Norway to develop large scale urchin harvesting. The increasing sea urchin demand and the shortage of sea urchins supply in the world market provide Norway with a unique opportunity to develop a profitable sea urchin harvesting industry. Initiations on urchin industries from Norwegian local private companies such as Kaston International has spread to different parts of the world in 2016. Developing sea urchin industry in Northern Norway will not only affect local economy and ecosystem services, but also have effects on marine ecosystem and habitats in the northern coastal region and support blue growth. The effects of kelp recovery such as carbon storage could contribute to the both Norwegian national GHG emission reduction but also the new goal of COP21 Paris meeting. Tourism and tourist fishing industry could be another important benefit for local community. The project establishes a knowledge base for estimating the effects of a potential sea urchin harvesting industry on ecosystem and habitat recovery and the effects on ecosystem services and economy in the local communities, and to develop an integrated management strategy for social-ecological system and sustainable industry development. The project is the first comprehensive study on ecological and economical sustainable industry development of sea urchin harvesting with consideration on how urchin harvesting will affect kelp-urchin dynamics and marine ecosystems as well as its impact on ecosystem services and economy in the Northern Norway. The knowledge is highly demanded by both local fishery management, national and international environmental NGOs as well as the publics.

Published Results/Planned Publications

Arujo RM, Assis J, Airoldi L, Barbara I,Bartsch I , Bekkby T, Christie H (2016) . Status, trends and drivers of kelp forests in Europe: an expert assessment. Biodiversity and Concervation. BIOC-D-15-00974R3

Christie H and Chen, W. 2016. Grønn vekst langs kysten . DN debat http://www.dn.no/meninger/debatt/2016/08/08/2121/Milj/grnn-vekst-langs-kysten

Christie H, H Gundersen, E Rinde, KM Norderhaug, C W Fagerli, T Bekkby, J K Gitmark, T Petersen. Can multitrophic interactions and climate change regulate large scale kelp-sea urchin distribution. (Resubmitted after review)

Christie H m fl. 2015. Sukkertare i nord: En glemt naturtype og ressurs på frammarsj etter 45 års fravær. Foredrag Norske Havforskeres Forening, Årsmøte 2015.

Christie, Hartvig NIVA, KJell Magnus Norderhaug, NIVA, Stein Fredriksen, University of Oslo, Pathrik Kraufvelin, Aabo Akademi University. 2015. How can kelp and seagrass beds persist being both food and habitat? Foredrag og abstract EMBs50

Talk at the 11th International Temperate Reef Symposium (ITRS), Pisa, Italy, 2016:

H Christie, E Rinde, C Fagerli, T Pdersen. Restoration of kelp forest ecosytems after 45 years of sea urchin grazing.

James, Phil. 2016. Commercial scale sea urchin roe enhancement in Norway, NOFIMA report.

Chen W., Berck P. , Christie, H., Gundersen, H., James, P., Armstrong C, Vondolia C. Sea urchin harvesting in Norway: a sustainable social-ecological system, work in progress

Vondolia C., Armstrong C, Chen W et al . Fishery and kelp habitat recovery, an example from Northern of Norway, work in progress.

Communicated Results

A **pre-kick-off meeting** with all the partners was held on 2-3 May 2015 in Oslo: NIVA, NOFIMA, UC Berkeley, UiT (via skype) and KASTON joined the meeting. Each participants presented their plan for their responsible working packages. Interaction and how to collaborate between WPs were discussed. An improved bioeconomic model for urchin harvesting were made for WP2

There were numerous small meetings within each working packages among all the partners during the year.

Another **end of project meeting** in 2017 was in planning with collaberating potential with EU Northern periphery project URCHIN led by NOFIMA.

Dissemination 1: One popular article on “Grønn vekst langs kysten” on DN and Aftenposten.

Dissemination 2: NIVA, NOFIMA collaborated with KASTON International, an industry partner who interested in urchin harvest and aquaculture, on 24 October, met one of the biggest Canadian aquaculture and sea food research institute on further promoting the ECOURCHIN idea to Canada.

Dissemination 3: NIVA on 26 October presented ECOURCHIN project to the Chinese Ambassador in Norway during their visit to NIVA Oslo.

Dissemination 4: Part of the results this year will be presented at Fram Science Day on 10 November 2016.

Dissemination 5: ECOURCHIN project idea was conveyed also on the Norwegian -South Africa week in October 2016 in Cape Town.

Communication in 2015

A **pre-kick-off meeting** between NIVA and NOFIMA on 12 March 2015: discuss the synergy between ECOURCHIN and URCHIN (EU Northern Periphery and Arctic Program). Data and results sharing among the two projects were agreed upon.

Kick-off meeting on 4 May 2015: The kick-off meeting was hold via skype due to the limited funding this year. NOFIMA, UiT and NIVA discussed the plan for the project this year and each institute. Action plan was made during the meeting. UC Berkeley was in a roll of consultancy this year due to the budget limit.

Discussion on economic modelling was done via two meetings on 20 May and 11 June in Tromsø between NIVA and UiT.

Dissemination 1: ECOUCHIN project idea is promoted among Norwegian and international urchin harvesters from Finland, Scotland and Canada during the NOFIMA URCHIN (EU) prject kick-off meeting on 19 May in Tromsø Local industry on urchin industry.

Dissemination 2: NIVA is collaborating with Kaston International, an industry partner who interested in urchin harvest and aquaculture to further promoting the idea to e.g. USA, Hellas, Japan and Netherland.

Dissemination 3: ECOURCHIN project was NIVA flagship project on Oslo Forskningstoget on 18-19 Setember. The idea of "sustainable harvesting/eating sea urchins and saving the kelp forest" were presented to the general public particularly school children.

Dissemination 4: Part of the results will be presented at Fram Science Day in November 2015.

Dissemination 5: An article on Aftenposten of the project is under preparation, a NIVA report and a manuscript.

Dissemination 6: Aseminar had be hold in Tromsø in November 2015 where results and project idea has been presented within the project group.

Interdisciplinary Cooperation

ECOURCHIN is a project cross several disciplines. The research team has expertise on biology, ecology, economics and geology. This year we also included one industrial partner as our associated partner to provide more information and needs from urchin industry. The project results further strengthen the interdisciplinary network BLUE FOREST between NIVA, IMR and Grid Arenda.

Budget in accordance to results

Funding from MIKON is the only direct funding for the project and has been essential to perform the studies planned in the project. There is no other funding sources.

The funding from the FRAM center "Fjord and coast" flagship to project " Recovery of coastal kelp ecosystems -driven by climate change or predators?" has provided newest sampling data for urchin density and urchin-kelp dynamics.

The funding from MIKON will provide vital source for successful knowledge development of the upcoming urchin industry in Norway and for sustainable development of the industry together with the ecosystem benefits gained from kelp forest recovery in the long run.

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Could results from the project be subject for any commercial utilization

Yes

If Yes

Both the sea urchins and the ecosystem services derived from recovered kelp beds (e.g. fishery, tourism, kelp harvesting) have the commercial values. Local private fishery industry such as Kaston International and C-flows will benefit directly from our results on where and how much to fish the sea urchins so as to develop a profit and sustainable urchin harvesting industry. The fishery industry can also make use of our results to potentially adjust their fishing quotas in the North when kelp recovered. The coastal tourist industry and the new rising interest in kelp harvesting can also utilize our result directly in their planning. For example, our results will benefit future attention on tourism and word heritage area in Vega.

Conclusions

Our project provides the first knowledge on spatial and temporal harvesting advisories for sea urchin harvesting industry in Northern Norway. Our models and results of recovery of habitat, the kelp forest, will provide an forfront modelling tool for habitat governance and the essessment of benefits of both the new industry and the habitat recovery to local communities.

In 2017, we will include the urchin -kelp regime shift to bridge harvesting in barrens and harvesting along the kelp forest after kelp recovery is an important step make our results provide more practical guidance and more easily to be utilized by local government and fisherman.

In 2017 we also need to complete the study on the impacts of cultural service (tourism) benefits from kelp recovery and the interactions between the different ecosystem services. Our project will develop a new method in studying the integrated ecosystem services provided by habitat. The methods could be extended to other habitat restoration such sea grass, deep sea.