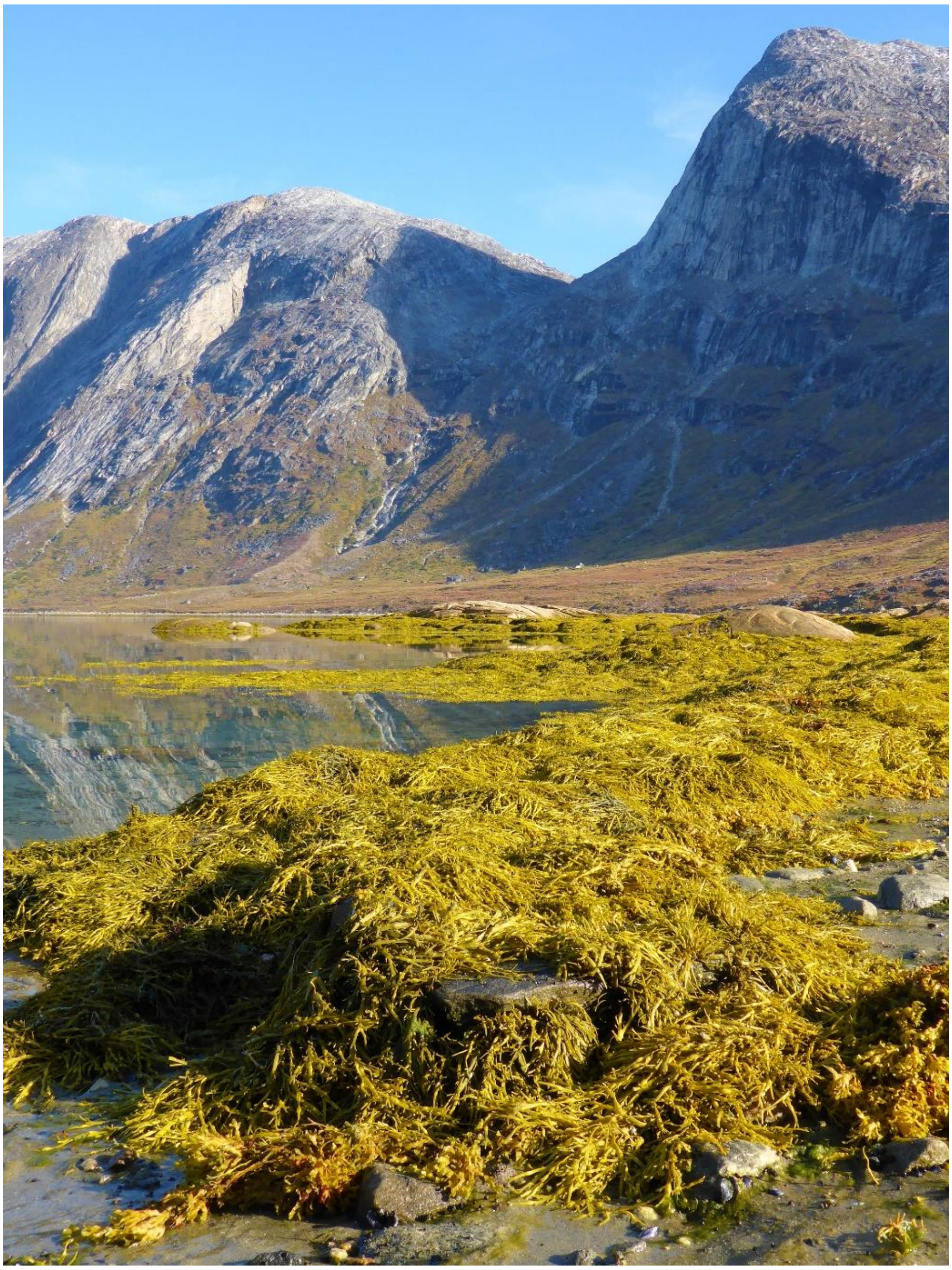
PINNGORTITALERIFFIK · GREENLAND INSTITUTE OF NATURAL RESOURCES

Sustainable Harvest of Seaweed in Greenland (SUSHi)

Optimising harvest • Minimising impacts



Scientific Report from Greenland Institute of Natural Resources

Susse Wegeberg & Ole Geertz-Hansen

Technical Report No. 115, 2021

Data sheet

Title:	Sustainable harvest of seaweed in Greenland (SuSHi). Optimising harvest. Minimising Impacts.
Authors:	Susse Wegeberg[1] & Ole Geertz-Hansen[2] (eds).
	Please see authors of separate chapters.
Institutions:	[1]Aarhus University, Department of Bioscience; [2]Greenland Institute of Natural Resources
Series:	Technical Report No. 115, 2021
Year of publication:	2021
Publisher:	Greenland Institute of Natural Resources
URL:	http://natur.gl
Financial support:	Nordic Council of Ministers' Arctic Co-operation Programme
Please cite as:	Wegeberg, S. & Geertz-Hansen, O. 2020. Sustainable harvest of seaweed in Greenland. Optimizing harvest, minimizing impact. Greenland Institute of Natural Resources, 45 pp.
ISBN:	87-91214-93-9
ISSN (electronic):	1397-3657
EAN:	9788791214936
Number of pages:	45
Internet version:	The report is available in electronic format (pdf) at http://natur.gl

Contents

Preface

This study aims to bend the bow from sustainable harvest to marked, as analysed with expertise from investigations of the Greenland tidal seaweed and kelp forest, environmental impact assessments of bulk harvest of kelp in Norway, experience from harvest and drying of seaweed as well as experience in job creation and seaweed marketing in Greenland and a seaweed industry in Nova Scotia, Canada.

The study includes 1) a literature review of seaweed harvest in general; methodologies and impact; 2) a workshop in Sisimiut, July 2017, titled Sustainable harvest of seaweed in Greenland (SUSHi). The workshop had six participant from Denmark, Greenland and Norway; 3) a monitoring programme outline based on 1) and 2); 4) proceedings from a visit at Acadian Seaplants in Nova Scotia, Canada; and 5) the workshop's recommendations for seaweed industry development in Greenland and identified knowledge gaps.

Thus, this report has five parts:

Part I Literature review of seaweed harvesting monitoring in relevant counties; Canada, Ireland, Norway.
Ole Geertz-Hansen & Susse Wegeberg

Part II Workshop; Key points and outcome.

Susse Wegeberg, Henning Steen, Kjersti Sjøtun, Ulrik Lyberth, Klaus Berg & Ole Geertz-Hansen

Part III Monitoring programme outline.
Susse Wegeberg, Ole Geertz-Hansen, Kjersti Sjøtun, Henning Steen, Ulrik Lyberth, Klaus Berg

Part IV Acadian Seaplants, Nova Scotia, Canada. Knowledge transfer from visiting:

- Seaweed extract plant and the James S Craigie research Centre in Cornwallis
- The drying and milling facilities in Yarmouth
- Harvest at Clark's Harbour
- On land cultivation facilities at Shag Harbour
- Department for Fisheries and Aquaculture by Wendy Vissers

Susse Wegeberg & Ole Geertz-Hansen

Part V Seaweed industry development in Greenland, recommendations and identified knowledge gaps.

Susse Wegeberg, Henning Steen, Kjersti Sjøtun, Ulrik Lyberth, Klaus Berg & Ole Geertz-Hansen

The project was financially supported by the Nordic Council of Ministers' Arctic Cooperation Programme.

Summary

The global seaweed industry is growing 5 – 6% per year and while wild harvest is less than 5 % of the total production it still amounts to about a million tons per year worldwide. Despite the vast resource available along the extensive coastline, harvest of seaweed for industrial purposes is still its infancy in Greenland, and only few licenses have been issued. The administrative procedure is not easy for the new local entrepreneurs.

We have identified a need for guidelines and an administrative practice that promote a future ecologically and economically sustainable use of the common seaweed resource in Greenland. This report contributes to that with 1) a short literature review, 2) proceeding from a workshop in Sisimiut on Sustainable seaweed harvest in Greenland, 3) an outline of monitoring programs supporting sustainable use of the seaweed resource 4) knowledge transfer from Acadian Seaplants Ltd in Nova Scotia, Canada and from the local Nova Scotia authorities responsible for the management of the resource, and at last 5) identification of bottlenecks in developing a sustainable seaweed industry in Greenland, and of knowledge gaps for a future development.

The literature reviews emphasize the need for management adapted to local species composition and environment conditions, but also to socioeconomic conditions and e.g. ownership of the land. Kelp and intertidal seaweed are key organisms structuring and fueling the ecosystem. Hence, overexploitation of the resource may, in addition to reducing the yield, impact other parts of the ecosystem's foodweb, e.g., fish and birds.

The workshop provided valuable insight and experience from Greenland and Norway covering the seaweed ecology, harvest methods, local administrative practices, economy, and the international selling market. The outcome was some recommendations for the emerging seaweed industry in Greenland, outline for a baseline and monitoring programme, and identification of knowledge gaps with respect to development of a sustainable seaweed harvest in Greenland.

A baseline and monitoring program was outlined based on the questions it should answer. Biological key components and methods were discussed for different harvest intensities.

Visiting Acadian Seaplants Ltd provided insight in a multi-million-dollar seaweed industry mainly based on harvesting of *Ascophyllum nodosum* and *Chondrus crispus* culture as well as developing innovative end products of high value based on scientific achievements.

The Department for Fisheries and Aquaculture, Nova Scotia, provided us with detailed insight into the complex management of the valuable but limited seaweed resource through licensing, quotas, and a strict stock assessment and monitoring program.

Bottlenecks and barriers for the development of a sustainable seaweed industry based on harvest are identified: Estimates of standing stock of harvestable seaweed and regrowth rate are lacking. The administrative process is time consuming and difficult to handle for the local small-scale entrepreneurs, partly because seaweed harvesting is not anchored properly in the

administrative system. Hygienic requirements of drying seaweed are considered to be unnecessary high, which lead to drying of seaweed as a bottleneck and a barrier for the harvest and drying in the settlements.

Several important knowledge gaps are identified. Among others: Standing stock, regrowth and recolonization estimates for different regions and climate zones. Holistic surveys of kelp forest to identify impacts from harvest and potential cascade effect on e.g. birds and fish. Harvest strategy and methodology. Drying methodology. Review of requirements for export of seaweed worldwide. Requirements for certification of sustainable harvest (Ø, ASC-MSC). Marketing of Greenland as a quality brand, design, storytelling, etc.

Sammenfatning

Den globale tangindustri vokser med 5 – 6% pr. år, og mens høst af tang er mindre end 5 % af den totale produktion, så beløber det sig til omkring en million tons pr. år på verdensplan.

Til trods for de forventede store mængder af tang langs Grønlands enorme kyststrækning så er kommerciel tanghøst stadig i sin vorden i Grønland. Tildelingen af høstlicenser er kun få, og den administrative procedure er ikke let at gå til for nye lokale iværksættere.

Vi har kortlagt behovet for vejledning og en administrativ praksis, der kan promovere en fremtidig økologisk og økonomisk bæredygtig udnyttelse af tangressourcerne i Grønland. Denne rapport bidrager til en sådan proces med 1) et kort litteratur-review, 2) konklusionerne fra en workshop i Sisimiut med titlen: Sustainable seaweed harvest in Greenland, 3) en skitse til hvad et overvågningsprogram bør indeholde, og som skal understøtte en bæredygtig udnyttelse af tangressourcerne, 4) vidensoverførelse fra et besøg hos Acadian Seaplants Ltd i Nova Scotia, Canada samt fra besøg hos myndighederne i Nova Scotia, som er ansvarlige for reguleringen deres tangressource, og til sidst 5) identifikation af flaskehalse i forbindelse med udvikling af en bæredygtig tangindustri i Grønland, herunder vidensbehov til fremme af en ønskelig udvikling.

Litteratur-reviewet understreger behovet for en regulering, der er tilpasset den lokale artssammensætning og miljøforhold samtidig med at reguleringen tilpasses de socioøkonomiske forhold og generelle ejerskab. De store bladtangsarter og tangen i tidevandszonen er således nøgleorganismer i økosystemer, hvor de er habitatdannere og også udgør et fødegrundlag for højere led i fødekæden. En overudnyttelse af ressourcen kan derfor, udover at resultere i mindre høstudbytte, også føre til indvirkning på fx fiske- og fuglepopulationer.

Workshoppen gav en værdifuld indsigt i erfaringerne fra Norge og også Grønland, herunder tangøkologi, høstmetoder, lokal/national administrativ praksis, økonomi, og det internationale marked for tangprodukter. Workshoppen resulterede i anbefalinger for den gryende tangindustri i Grønland, en skitse for hvad overvågningsprogrammer i forbindelse med tanghøst bør indeholde, samt kortlægning af videnshuller i forhold til en bæredygtig tanghøst i Grønland.

Skitsering af et overvågningsprogram blev baseret på hvilke spørgsmål et sådant skal kunne besvare. Biologiske nøglekomponenter og metoder blev diskuteret i forhold til de forskellige metoders høstintensitet.

Besøget hos Acadian Seaplants Ltd i Nova Scotia, Canada, gav indsigt i et multi-million-dollar tangindustri. Industrien var hovedsageligt baseret på høst af buletang (*Ascophyllum nodosum*) og dyrkning af *Chondrus crispus*. Derudover havde firmaet en stor forskningssatsning på udvikling af innovative og høj-værdi slutprodukter.

Ministeriet for Fiskeri og Akvakultur (Department for Fisheries and Aquaculture) i Nova Scotia, gav os en detaljeret indføring i den komplekse

regulering af den værdifulde, men begrænsede tangressource gennem tildeling af licenser, biomassekvoter og krav om kortlægning af ressourcen samt overvågningsprogram.

Til sidst er flaskehalse og barriere for udvikling af en bæredygtig udnyttelse af den grønlandske tangressource kortlagt, herunder manglende estimater for den høstbare tangressource samt genvækst. Den administrative proces er vurderet til at være tidskrævende og svær at håndtere for en lokal iværksætter. Dette skyldes til dels at tanghøst ikke er rigtigt forankret i det administrative system. Derudover mener man, at de sundheds krav for tørring af tang er unødvendigt høje hvorved tørringen bliver en stopklods for høst og tørring af tang i bygderne.

Adskillige videnshuller blev kortlagt, bl.a.:

Viden om tangressourcens størrelse, genvækst og rekolonisering i forskellige regioner og klimazoner i Grønland

Økologiske undersøgelser af tangskov til kortlægning af indvirkning af høst og evt. kaskadeeffekter på fx fiskearter og fugle

Udvikling af høststrategier og –metoder

Undersøgelser af tørringsmetoder

Undersøgelse af kravene i forbindelse med en eksport af tangprodukter

Behovet for certificering af bæredygtig tanghøst (Ø, ASC-MSC)

Hjælp til markedsførelse af et Grønland, som producere kvalitetsprodukter, herunder hjælp til design og historiefortælling (*story-telling*) mm.

Eqikkaaneq

Nunarsuaq tamakkerlugu qeqqussanik tunisassiorneq ukiumut 5-6 %-inik annertuseriartarpoq. Naak qeqqussanik pinngortitami nammineq naasimasunik tunisassiorneq nunarsuarmi tamakkiisumik tunisassiarineqartartut 5 %-iinit annikinnerugaluartut, taamaattoq tunisassiarineqartartut million tonsit ukiumut angusarpai.

Kalaallit Nunaata sineriaa isorartugaluaqisoq aammalu qeqqussanik amerlasuunik peqarsorinaraluartumi, oqartariaqarpugut qeqqussanik tunisassiorneq aatsaat aallarnisarniarneqalermat. Qeqqussanik katersinissamik akuersissuteqarfigineqarsimasut ikittuinnaapput, nunaqavissullu qeqqussanik tunisassiulerusukkaluartut pappiararsornertaatigut allaffissornertaatigullu piumasaqaataasunut malinninniarnermikkut tusiapittarlutik.

Allaffissornertaata aaqqissuunneqarsinnaaneranik aammalu ilitsersuutinik pisariaqartitsinerit suunerinik misissuilaarnikuuvugut, neriulluta Kalaallit Nunaanni qeqqussanik tunisassiornerup piujuartitsiniartumik aningaasarsiornikkullu illersorneqarsinnaasumik ingerlanneqarsinnaaneranik soqutiginnilersitseqataassalluta. Nalunaarusiaq una taama ingerlatsisoqarsinnaaneranik makkunuunatigut ikorfartuivoq: 1) Ilisimasanik aallerfiusinnaasunik allaaserinninneq, 2) Sisimiuni ataatsimiinnermit naggasiutitut inaarutaasut, ataatsimiinneq qulequtserneqarsimavoq ”Sustainable seaweed harvest in Greenland”, isumaqartoq Kalaallit Nunaanni piujuartitniarnermik toqqammaveqarluni qeqqussanik iluaquteqarneq”, 3) Qeqquarniartarnerup alaatsinaanneqarluni misissuiffigineqartarnissaanut pilersaarutigineqarsinnaasutut siunnersuut – taamaalilluni piujuartitsiniartumik ingerlanneqartuaannarnissaa qulakkeerniarlugu, 4) Canadami Nova Scotiami oqartussat qeqquarniarnermi aqutsinerannit kiisalu Canadami namminersorlutik qeqqussanik tunisassiortut ”Acadian Seaplants Ltd-kkut ilisimasaannik Kalaallit Nunaannut anngussinissaq, naggataagullu, 5) Kalaallit Nunaanni piujuartitsiniartumik qeqqussanik tunisassiornermik ineriartortitsinermi aporfigineqartartut suussusersineqarnissaat ilanngullugu aamma ineriartortitsiniarnerup kissaatigissat naaperlugit ingerlanneqarnissaa anguniarlugu ilisimasassanik sunik pisariaqartitsinerup qulaajaaffigineqarnissaa.

Ilisimasanik aallerfiusinnaasunik allaaserinninnerup erseqqissisippaa qeqquarniartitsisarnerni sumiiffigisami immap naasoqatigiivisa katitigaanerinut aammalu avatangiisaanut naapertuuttumik aqutsisoqartariaqartoq. Qeqquarniartitsisarnernut atatillugu paasisassarsiornitsinni erserpoq sumiiffigisami innuttaasut akornanni aningaasarsiornikkut sunniutaasunut aammalu nalinginnaasumik piginnittussaatitaanermik apeqqutinut tunngassuteqartutigut naleqqussaasoqartariaqarneranik pisariaqartitsisoqarnera.

Equutit angisoorsuit qeqqussallu tinittarnerup ulittarnerullu killingini uumassusillit ataqatigiiaarfiini qitiusumik pingaaruteqarlutik inissisimapput, taakkumi uummavinnik pilersitsisuusaramik, uumasullu nerisareqatigiiaartarneranni qullasinnerusuniittunit nerineqartarlutik aamma. Taamaalillutik pineqartut taakku piiarneqarpallaalerunik, iluanaarutissat ikiliinnaratik aamma assersuutigalugu aalisagaqassutsimut timmiaqassutsimullu sunniuteqarsinnaapput.

Sisimiuni ataatsimiinneq paasissutissarpassuarnik, pingaartumik Norgemi Kalaallit Nunaanilu qeqqussat imaani uumassusilinnut ataqatigiiffiinik kiisalu qeqqussanit tunisassiornermit misilittagaalersunik, pissarsiviulluaqaaq. Ataatsimiinnermi Kalaallit Nunaani qeqqussanik tunisassiuleriartornerup allarnisarfigileruttugaani inaarutaasumik innersuussuteqartoqarpoq, qeqquarniarnerup misissuisarnertigut alaatsinaanneqarnissaanut iliuuserineqarsinnaasutut siunnersuutit kiisalu Kalaallit Nunaanni piujuartitsiniartumik qeqqussanik tunisassiornissani ilisimasat amigaataasut suussusersineqarnissaat suliniutigineqaqquvoq.

Qeqquaqassutsip alaatsinaanneqarluni misissuiffigineqartarnissaanik pilersaarutigineqarsinnaasutut siunnersuummi tunngavigineqarput apeqqutigineqarsinnaasut suusut akissutissarsineqartarnissaat. Soorlu eqqartorneqartut ilagaat uumassusilerinermi qitiusumik pingaarutillit suunerat aammalu qeqqussanik tunisassiornermi qanoq akulikitsigisumik qalluisarnissat kiisalu katerseriaatsit periuserineqarsinnaasut ilanngullugit.

Canadami Nova Scotiami Acadian Seaplants Ltd-kkut paasisassarsiorfigineranni millionilippassuarnik dollarinik aningaasarsiutigigaat paasinarpoq. Pingaarnertut qeqqussat ilaat sapangaasat (*Ascophyllum nodosum*) tunisassiarineqarput aammalu equutit ilaat (*Chondrus crispus*-ikkut). Tamakku saniatigut isertitaqaataalluartumik tunisassiarineqarsinnaasut allat nutaat suliffeqarfiup sukumiisumik ilisimatusaatigitippai.

Nova Scotiami Aalisarnermut Immamilu Naatitsisarnernut assigisaanullu Naalakkersuisoqarfik (Department for Fisheries and Aquaculture) qeqqussanik (tunisassiarineqarsinnaasut killeqaraluaqisut) katersinissamut akuersissutinik, peqassuseq tunngavigalugu qallugassartassiissutit aammalu qeqquaqarfiit nalunaarsorneqartarnerinut piumasaqaataasartut kiisalu misissuisarnertigut peqassutsip alaatsinaanneqarnissaanik pilersaarusiortarnerni piumasaqaataasartunut tunngassuteqartunik paasissutissarpassuarnik sukumiilluinnartunik nalituunillu tunioraapput.

Naggataagullu innersuussutigineqarpoq nunatta qeqquaasa piujuartitsiniartumik iluaqutigineqanissaat anguniarlugu ineriartortinniarnerini aporfiit aporfissaasinnaasullu nalunaarsorneqarnissaat, ilanngullugu aamma qeqqussat tunisassiareriaannaasut qanoq annertutigisut qallorneqarsinnaanerinut missingersuutinik pigisaqannginneq naaqqittarnerinullu tunngassuteqartunik paasissutissanik katersinissat pisariaqartinneqarnerat erseqqissaatigineqarluni.

Nunaqavissut naliliipput qeqquarniartarnerup allaffissornertaata pisariunera piffissartornarneralu oqimaatsuusoq. Tamanna qeqquarniartarnerup allaffissornermut attuumassuteqarpallaannginneranik tunngaveqarpoq. Tamakku saniatigut aamma qeqqussanik panersiisarnermi peqqinnissaq pillugu piumasaqaatit pisariaqanngitsumik sukangavallaarnerat, pissutsillu tamaannerat peqqutaalluni nunaqarfinni qeqqussanik tunisassiorsinnaaneraluit qatangiinnartarnerat tikkuarneqarpoq.

Ilisimasatigut amigaataasut nalunaarsorneqartariaqartut, soorlu makku:

Qeqquaqassutsip annertussusaata ilisimasaqarfiginissaa, taamatullu naaqqittarnerinut inissiffisseqqittarnerannullu nunatsinni nunap immikkoortuini silamillu atugassaqarfigisaanni assigiinngitsuni pissusaat pillugit paasissutissanik pissarsinissaq ilanngullugit.

Qeqquaqarfinni ilanngartuinerup tamatumalu uumassusillit ataqatigiiffiinut sunniutaanik, matumani uumassusillit nerisareqatigiiaarnerat eqqarsaatigalugu kingunerinik misissuisarnissat pineqarlutik.

Qeqqussanik qallueriaatsit ineriartortinneqarnissaat.

Qeqqussanik avammut tunisassiorniarnermi piumasaqaatinik misissuinissat.

Qeqqussanik tunisassiornerup piujuartitsiniarnemik tunngaveqarneranik uppernarsaammik pissarsiniarnissaq (Ø, ASC-MSC)

Kalaallit Nunaata pitsaalluinnartunik tunisassiaqarneranik piseqqusaarusiornissanut ikiorneqarnissaq tunisassiarineqartunut tunngassuteqartut ilanngullugit, soorlu poortuutit, aammalu tunisassiap oqaluttuassartaata soqutiginartup kusanartumik saqqummiunneqarnissaannut ikiorneqarnissaq

1 Introduction

Susse Wegeberg & Ole Geertz-Hansen

Seaweed harvest, beside local and traditional use is in its infancy in Greenland, but medium to large scale harvest has been discussed several times in the past. It is therefore important to have regulation on sustainable, ecological and economic, seaweed harvest in Greenland in place.

Several issues has been raised 1) Yield optimisation by developing local adapted strategies and establishing monitoring programmes in order to minimize the ecological impact and promote sustainability 2) quality optimisation; and 3) identification of marked and product branding with reference to the unique quality of arctic/Greenland seaweed products, the Arctic environment and, for instance, Inuit traditions and traditional recipes and anecdotes (story telling).

1.1 Background

Seaweed biomass is a marine resource, which receive increased attention in present years. Besides its obvious use for human consumption, seaweed extracts are also used industrially; in functional foods, cosmetics and as soil fertilizers (Wegeberg & Felby 2009; http://bio4bio.ku.dk/documents/nyheder/wegeberg-intro-til-alger.pdf). Furthermore, for the last decade, research in using the seaweed biomass for bioenergy and in biotechnology, has been quite intense (Wegeberg & Felby 2010; http://bio4bio.ku.dk/documents/nyheder/wegeberg-alage-biomass.pdf).

Harvest and cultivation of seaweed species are in industry scale in Asia, and e.g. Canada and Norway, while still in its cradle in Greenland. The amount of harvested seaweeds from wild stocks is relatively stable and has been fluctuating between 1-1.3 million tons per year since 2000 (MacMonagail et al. 2017). All three main seaweed groups are subject to harvesting worldwide, but the most important groups are rockweed (*Ascophyllum nodosum*), kelps (e.g. *Laminaria hyperborea*, *Macrocystis pyrifera*, *Ecklonia maxima*) and some genera of red algae (*Gracilaria* spp., *Gelidium* spp.)).

It is expected that large biomasses of seaweed are present along the extensive coastline of Greenland. Preliminary investigations of seaweed biomasses in South Greenland (Nordic Seaweed Project, 2004-2007) show biomasses of up to 8 kg wet weight per m^2 and a coverage percentage of up to 100 % until depths of more than 20 m (Wegeberg 2007, Krause-Jensen et al. 2012).

1.2 State of seaweed harvest and regulation in Greenland

The regulation for seaweed harvest in Greenland is handled by the Department for Fisheries, Hunting and Agriculture although the legal basis is unclear. At present, several licenses for seaweed harvest along the Greenland west coast has been awarded, and an executive order is being developed.

Until now, the permissions included definitions of species, area, harvest methodology and harvest period. Furthermore, reporting on harvested species and biomass has been required. The harvest amount applied for has been relatively small, and consequently, there has been no requirements of monitoring as well as studies on regrowth and impact has yet not been carried out (N.M. Lund, pers. com.).

If future large scale-harvest shall be sustainable, a monitoring program has to be developed along with an optimized harvest strategy. It is assessed that a monitoring program is necessary to assure future sustainable harvest with regard to maintaining the seaweed communities' biodiversity and adapted to different scales of harvest in order to optimize yield and to maintain the biological functionality of the seaweed community at large.

1.3 Development of a monitoring programme

Seaweeds create communities in the tidal and subtidal zones and as kelp forest. They sustain a complex habitat and ecosystem, which serve as nursery grounds for associated fauna (Dunton & Schell 1987, Norderhaug et al. 2005, Christie et al. 2003, 2009; Lippert et al. 2001; Wlodarska-Kowalsczuk et al. 2009). Furthermore, the seaweeds provide feed for grazing animals but also as particulate organic material (POM) (e.g., Fredriksen 2003, Renaud et al. 2015), a contribution which also must be considered when managing seaweed harvest (Halat et al. 2015, Ugarte et al. 2017, Garbary et al. 2017). As a consequence, it is difficult to identify and predict cascade effects from seaweed harvesting without detailed studies, of which there at present are only few in Greenland (Wegeberg 2007, Wegeberg et al., upubl. data). However, a large-scale experimental study in Norway, showed that large-scale disturbances on habitat-forming species have ecological consequences that extend beyond the decline of the single species to affect multiple trophic levels of the broader ecosystem. (Norderhaug et al. 2020).

Hence, a monitoring programme must be designed and support to identify all potential effects of harvesting; to minimize impacts but also to optimize yield if seaweed harvest is scaled up. In addition, the monitoring programme can form base for a potential certification of the Greenland seaweed harvesting. The Marine Stewardship Council (MSC) and Aquaculture Stewardship Council (ASC) has developed standards for harvesting of wild seaweed (https://www.asc-aqua.org/wp-content/uploads/2017/11/Get-Certified-Guide-Seaweed.pdf).

1.4 Harvest methodologies and drying; efficiency and quality

Different methodologies for harvesting seaweeds has been developed in different countries and adapted according to target species, depths, tides and other environmental conditions. In some countries seaweeds are harvested by rake and hand at low tide (Canada, Ireland) and in some it may be more or less mechanised (France, Norway and Iceland, (see chapter 5).

For Greenland it has proven relatively efficient to collect loose-lying kelp (e.g., *Saccharina longicruris*) and with a dingy anchor pulled by hand (Ulrik Lybeth, pers. comm.).

Harvest strategies may also be different according to species; In New Brunswick the intertidal seaweed species (in particular *Ascopyllum nodosum*), is harvested with a handheld rake, which rely on thinning of the seaweed biomass and continued growth of the established vegetation, and hence not need recolonisation of the seaweed vegetation (Ugarte et al. 2006). In, Norway, the harvest of *Laminaria hyperborea* is by a mechanical rake from ship, which remove most of the biomass, however, with the rationale that younger and smaller specimens are left to grow and re-establish kelp forest in the harvested area, usually within 4 years (Steen et al. 2016).

Therefore, the choice of harvest methodology and strategy is most important with respect to impact, and need to be selected and studied in detail, for instance by a "before-after-control-impact" (BACI) fauna studies or observation. The monitoring programme should be designed to support the choice of harvest gear.

Drying methodology of the harvested seaweed may influence the final quality of the seaweed products. At the moment it is not fully investigated how specific seaweed biomass shall be dried in Greenland in order to obtain best quality, slowly or quickly in direct sun (Seaweed session, Commercialisation of Science in Greenland, workshop in Nuuk, 17th -18th November 2015). At present, the stipulations by the authorities regarding drying of seaweed in Greenland for human consumption that it shall be roofed and protected by fly nets of hygienic reasons.

1.5 Marketing; marked and story telling

For establishing a sustainable business on dried seaweed in Greenland, five questions have been developed for use in marketing analysis, job creation and socio economics:

1) How can seaweed harvest and use be developed in Greenland in a sustainable manner, and create jobs and income, also for the settlements?

2) How can the locals in a simple and efficient manner be educated in seaweed harvesting and processing of the seaweed biomass in Greenland to ensure and improve product quality?

3) Which local seaweed species/products will have potential for the world market, and how will this influence sustainability, quality, jobs and options for income?

4) How can the seaweed biomass be processed in Greenland with respect to the parameters mentioned in 3), and match the demand of the world marked while adding value to the products, including branding, at the same time?

5) Which market survey should be conducted and how can the world market be prepared for the Greenland seaweed product in order to select products as mentioned in 4)?

2 Review of seaweed harvest management, impact, and regulation / socio economics

Ole Geertz-Hansen & Susse Wegeberg

The key points from a literature review (Table 1) can be organised into:

1. Management; harvest strategy, methodology and yield
2. Harvest impact on seaweed community
3. Regulation and socioeconomics

Table 1. Key points of literature review including seaweed harvest management, impact and regulation.

Reference	Topic/species / location	Key points
1. Management; harvest strategy, methodology and yield		
Bailey & Owen (2014)	Advice regarding harvest methodology for edible seaweed species in England	Tables 3, 4 and 5 for brown, green and red seaweed species, respectively
Guiry & Morrison (2013)	Sustainable harvesting of *Ascophyllum nodosum* in Ireland	It is assessed that 159,000 (±45,000) and 75,000 wet tons were available for harvesting. The large difference is due to the methods employed, but there are sufficient unharvested areas to satisfy any requirements for conservation.
Seeley & Schlesinger (2012)	Sustainability of *A. nodosum*	*Ascophyllum* fits all criteria for large impacts on the rest of the ecosystem; low-trophic level, high proportion of biomass, highly connected in the food web.
Ugarte & Sharp (2001)	A new approach was applied to the management of *A. nodosum*; maximum exploitation rate, cutting height, gear restrictions, and protected areas were management measures within a precautionary pilot harvest plan	The consensus was that the harvest impact on the habitat architecture was minimal and of short duration, therefore, it was advised to continue the harvest but to maintain the precautionary approach to management.
Vandermeulen (2013)	Review; harvest of *Chondrus, Ascophyllum*, kelp	Recommendations for regulation; landing registration, harvest methodology (tine spacing), closed areas etc.
Vea & Ask (2011)	The Norwegian sustainable harvest management plans of *Laminaria hyperborea*	a sustainable management program for the harvest was created with a 5-year cycle and rotating zones in fields

Vega et al. (2014)	Comparison between harvest areas of *Lessonia nigrescens* managed by Management Areas for Exploitation of Benthic Resources (MAEBR) and Open Access Areas (OAA)	The ecological indicators reinforced the concept of co-management in MAEBR as a viable harvesting administration system along the Chilean coast, and indicated a high-harvesting pressure in OAA.
Gonzáles et al. (2014, 2015)	Coalescence in *Lessonia spicata* and *L. berteroana*	Harvest methodology should be considered with respect to genetic sustainability; Gene pool exchange through holdfasts; the adaptive values of coalescence in these species should be evaluated.
2. Harvest impact on seaweed community		
Kelly (ed.) (2005)	Assessment of the likely threats of seaweed harvesting incl. potential impacts on marine birds, fish, invertebrates, flora and productivity	In general, mechanical kelp harvesting should not be conducted near important areas for birds. The ecosystem effects of mechanical kelp harvesting are likely to depend on harvesting frequency, harvesting intensity and biomass removal rates, and with an ecosystem approach, careful management and regulation for a sustainable kelp harvesting industry, the potential for impacts upon birds can be minimised
Kelly et al. (2001)	Effect of mechanical and hand harvesting on *A. nodosum* regeneration and biodiversity	Richness varied over time but an effect of harvesting was not detected. *A. nodosum* was nearing recover after 11-17 months.
Levitt et al. (2002)	*Ecklonia maxima*; the effects of kelp harvesting on its regrowth and the understory benthic community and a new method of harvesting kelp fronds	Although harvesting of whole kelp has a minimal effect on the understory biota and kelp itself recovers within two years, selective cutting of fronds allows plants to remains alive and produce a higher yield. This method is likely to minimize damage to the kelp bed system
Lorentsen et al. (2010)	Great cormorant foraging efficiency in relation to harvest intensity of *L. hyperborea*,	Seaweed harvest leads to decrease in fish abundance and hence foraging efficiency
Nordenhaug et al. (2020)	Ecosystem-level effects of large-scale disturbance in kelp forests	Large-scale experimental disturbances on habitat forming species (*Laminaria hyperborea*) have ecological consequences that extend beyond the decline of the single species to affect multiple trophic levels of the broader ecosystem including invertebrates and fish.
Rothman et al. (2006)	The effects that different harvesting methods have on the growth of sub-canopy kelps, kelp population structure and kelp recruitment were tested in a kelp bed of *Ecklonia maxima*	Current frond-harvesting methods (lethal and non-lethal) do not affect the growth (stipe elongation) rate of sub-canopy *E. maxima* plants, their density or recruitment of juveniles in a shallow-water, dense kelp bed in South Africa

Sharp et al. (2006)	Ecological impact of Ascophyllum harvesting in Canada	At an exploitation rate of 17% it was not possible to detect changes in the structure of *A. nodosum* beds at a landscape scale.
Steen et al. (2015)	Harvesting of *L. hyperborea* in relation to fish and crab catch	Fish and crab catch in relation to kelp harvesting; no significant effects of kelp harvesting on fish and crab catches were observed
Steen et al 2016	Regrowth after kelp harvesting in Nord-Trøndelag, Norway	*L. hyperborea* biomass appeared restored 4 years after harvesting. Kelp recruits already present as understory vegetation prior to harvesting seems to have contributed to the restocking.
Vásquez et al. (2012)	Test the effects of *Lessonia nigrescens* harvesting on the following population variables: (1) abundance, (2) distribution, (3) juvenile recruitment, (4) plant morphology, (5) frequency of reproductive plants, and (6) biodiversity of the macroinvertebrate community associated to kelp holdfasts	Despite the enormous harvesting pressure on *Lessonia* density and biomass, the associated macroinvertebrate richness has been maintained, due to normal plant growth and high recruitment all year round
3. Regulation and socioeconomics		
Acadian Seaplants Ltd	ASL is a company with three commercial "legs": 1) Extract from Ascophyllum nodosum for biostimulant products in Cornwallis; 2) Dried and milled Ascophyllum (and Fucus vesiculosus) for animal feed in Yarmouth; 3) Cultivation of Chondrus crispus for Hana-Tsunomata™ in Charlesville. ASL employs about 600 persons in Nova Scotia, New Brunswick, Ireland and Scotland, and is a $ 100 million business.	See Chapter 5
Dunningham & Atack (2012)	NetAlgae; regulation of seaweed industry in Norway and UK	Presentation of regulation of wild harvest, seaweed cultivation and IMTA in the different regions
Regulation of seaweed harvest in Nova Scotia, Canada	Department for Fisheries and Aquaculture	See Chapter 5
Meland & Rebours (2012)	NetAlgae; The Norwegian seaweed industry	Provides an overview of the Norwegian seaweed industry, its history, evolution and current status, the document outlines the scale, scope, value and the key raw materials used by the industry. The regulatory and management systems in Norway is also described

MacMonagail et al. (2017)	Sustainable management of the "wild" seaweed resource	More than 1 million t harvested annually from wild stocks globally. Harvest and utilization of seaweed are often linked cultural identity of coastal communities. Ownership of the resource are important for sustainable management.
Vásquez & Westermeier (1993)	Factors influencing yield from natural beds of marine algae in Chile	(1) the pressure of international markets for raw material, (2) unemployment level of coastal workers, which increases the number of seasonal harvesters, (3) the low level of regulation enforcement along Chile's extensive coast, (4) the low level of education and income of algal harvesters, and (5) except for *Gracilaria,* the lack of a management plan for algal resources
Vásquez (2008)	Recommendations for a management program for sustainable harvest of Chilean kelp subjected to intense harvesting	(1) to harvest the entire plant including the holdfast; (2) to harvest plants larger than 20 cm in diameter; (3) to harvest plants sparsely, selecting mayor specimens; (4) rotation of harvesting areas; and (5) for Macrocystis, to cut the canopy 1-2 m from the surface.

2.1 Management; harvest strategy, methodology and yield

The direct effect of seaweed harvesting on local communities will depend mainly on the size of the affected area, on amount of biomass harvested per area unit, on regrowth capacity of the seaweed harvested and on the recruitment capacity and mobility of associated species. It may also depend on the harvesting method. For example, in the harvesting of *Ascophyllum nodosum* it is often underlined that removal of the whole plant or too much biomass should be avoided; since recruitment from germling stage is low (e.g. Ugarte 2011). If a certain part of the basal fronds are left intact, this may promote more rapid regrowth and also less impact of the harvesting on the rest of the intertidal community. This is on the other hand not the case for kelp species, where regrowth does not occur from the stipe parts, which may be left after harvest.

2.2 Cascade effects on seaweed supported communities

Cascade effects are large-scale effects involving several trophic levels and that lead to conspicuous changes in trophic relationships. A typical example is the impact of presence or not-presence of predators on sea otters on kelp habitat in the northeast Pacific. If sea-otters are hunted or predated on by man or killer whales, the reduction of sea otters leads to the formation of large sea urchin populations, which graze the kelp and form barren grounds. Whenever sea-otters are not subject to predation they will keep the sea urchins in check, and kelp forests will prevail (e.g. Estes et al. 1998).

Harvesting of *Laminaria hyperborea* removes the kelp canopy in smaller or larger patches or areas, with a corresponding severe impact on associated fauna and epiphytic algae. In studies of regrowth of *L. hyperborea* after harvesting in Norway, it has been found that while kelp biomass recovered relatively quickly, that it took much longer time for the associated fauna and flora to re-establish (Christie et al. 1998, Steen et al. 2015, Norderhaug et al. 2020). Local community effects have also been observed after harvesting of *L. hyperborea*. In a study of cormorant foraging on fish and the potential effect on this by removal of the kelp habitat by trawling, Lorentsen et al. (2009) observed that there were lesser densities of small gadoids in newly trawled areas.

3 Workshop; key points and outcome

Susse Wegeberg, Kjersti Sjøtun, Henning Steen, Klaus Berg, Ulrik Lyberth & Ole Geertz-Hansen

A workshop was held in Sisimiut 13.-15. June 2017 titled Sustainable harvest of seaweed in Greenland (SUSHi), and with following participants with their 2017 affiliations (Fig. 3.1):

Klaus Berg, senior advisor, Klaus Berg Consult, Denmark
Ole Geertz-Hansen, senior researcher, Greenland Institute of Natural Resources
Ulrik Lyberth, owner and founder of MAKI Seaweed Greenland
Kjersti Sjøtun, professor, Bergen University, Norway
Henning Steen, senior researcher, Institute of Marine Research, Norway
Susse Wegeberg, senior advisor, Aarhus University, Denmark

The workshop panel hence possessed expertise/experience in seaweed biology and ecology, harvest, drying and sale as well as marketing/innovation:

Please find the workshop programme in Appendix 1.

The workshop was initiated with presentations by the participants and experts on different areas. The key points of the presentations and subsequent discussions are compiled below.

Fig. 3.1. Participants of the SUSHi workshop in Sisimiut. Back row from left: Ole Geertz-Hansen, Ulrik Lyberth, Susse Wegeberg. Front row from left: Henning Steen, Klaus Berg, Kjersti Sjøtun.

3.1 Key points

3.1.1 Harvest and cultivation potential of kelp in Greenland

Seaweed species diversity, distribution (geographical and vertical) and biomass in Greenland (Susse Wegeberg)

- The number of species in the North Atlantic seaweed floras shows a linear decrease with increasing latitude. The Greenland seaweed flora has 137 species compared with 375 species in Denmark
- The Greenland flora has a higher proportion of brown algae species than flora from lower latitudes
- The dominant tidal zone species in Greenland are:
  Ascophyllum nodosum
  Fucus distichus
  Fucus vesiculosus
- Dominant Greenland kelp species are:
  Alaria esculenta
  Agaum clathratum
  Laminaria solidungula
  Saccharina latissima
  Hedophyllum nigripes
- The vertical distribution of species in the kelp forest shows a mix of species (*Agarum clathratum, Alaria esculenta, Saccharina* spp., *Hedophyllum nigripes*) until 20 m's depth. Thereafter *Agarum clathratum* is complete dominant until app. 40 m depth on the west coast of Greenland
- Presence of species and their biomass are determined by follow ecological factors/drivers:
  - Degree of wind / wave exposure
  - Ice scouring
  - Grazing by sea urchins
- Biomass of tidal seaweed vegetation may reach ca. 7 kg of wet weight in average in the Nuuk area
- Biomass of kelp may reach ca 4 kg of wet weight in average, but can reach a maximal biomass of 13 kg in the Qaqortoq area
- Content of iodine from a single specimen of *Saccharina litissima* from Greenland was 1400 µg /g, which corresponds to the iodine content of same species from Maine, US, and British Columbia, Canada.

The status of seaweed harvest in Greenland (Ole Geertz-Hansen)

From several workshops held during 2015 (Commercialisation of Science in Greenland, workhop in Nuuk, 17th -18th November 2015, Polarforskningskonferencen, Aalborg, 3rd -4th December 2015 (Wegeberg 2016)), it has become clear that administrative issues are challenging due to small one-man enterprises, where the same person must cover and perform harvest, packing, sale, marketing, development etc.

In Norway, kelp forests of mixed species (incl. *Saccharina latissima*) in fjords are not harvested. However, it is assessed that this could be an industry but is not exploited due to environmental considerations (standing stock decline as result of increasing temperatures leading to erosion of *S. latissima* (Armitage et al. 2017)) in comparison with the otherwise large biomasses of *Laminaria hyperborea* offshore. It is considered to produce *S. latissima* in Norway but then by cultivation. At present, the kelp cultivation, especially of sugar kelp, is on the rise in Norway and involve at present 8 companies (https://www.norwegianseaweedfarms.com/farmers

It is assessed that cultivation is a realistic alternative to harvest of Greenland kelp forest due to single species production and high quality.

It is also assessed that the potential for harvest and cultivation of kelp species equals those of Norway.

The level of harvest of *Ascophyllum nodosum* in Norway is not known due to lack of regulation (no harvest registration requirements) as the tidal zone belongs to land owners. Here it is hence not assessed the potential for harvest of fucoids in Greenland.

3.1.2 Regulation and monitoring requirements in Greenland

Maximal Sustainable Yield (MSY) (Kjersti Sjøtun, Henning Steen)

To regulate and monitor harvest of seaweed species, the re-growth rate is basic.

Sea urchins are considered as a dynamic and unpredictable stressor. It is well known from Norway and Greenland (e.g. Upernavik area) that areas exist where kelp forest is erased by sea urchins. In Norway the establishment of sea urchins is stable for an unknown period of time, where their excessive presence and continuous grazing prohibit the kelp to re-establish. This is in contrast to the known cyclic (ca- 4 year) relationship between kelp forest establishment and sea urchin bloom on the west coast of North America. In Greenland, it is unknown whether the relationship is cyclic or the *isoyake* situation is chronic or e.g. related to depletion of predators of sea urchin (Norderhaug & Christie 2009).

Some monitoring of environmental conditions would show changes, and make it possible to warn of possible stressors, and hence cumulative impacts from, e.g., temperature and salinity changes as a result of climatic changes and increasing glacier melting. As *Saccharina latissima* (*longicruris*) expresses optimal growth rates at 10°C, it is assessed that a rise in temperature may lead to an increased growth rate of the species until 10°C is reached.

The bryozoan *Membranipora membranaceae* has been introduced to the North-West Atlantic, and it may with increasing sea temperatures spread northwards to Greenland. It has proven to be a common epiphyte on kelp where it may cover the lamina and result in lowered yield and quality of kelp biomass.

In Norway, regulation stipulates harvest of strips of 1 NM every fifth year. However, there are trends that indicate a decline in harvest in the traditional regions, which may be assigned to less harvest effort (introduction of new harvest areas) or a decline in standing stock.

Methods used for biomass mapping and monitoring:

- Sampling by SCUBA divers
- Visual (video, ROV)
- Acoustic
- Remote sensing

Mapping of total kelp biomass in Norway is assessed to be insufficient, and hence the degree of harvest may be larger earlier presumed. Modelling of kelp biomass has been initiated.

Norway use video mapping in harvested and trawl-free reference areas. Established video transects are visited and analysed for kelp condition; canopy coverage, height, density, presence of sea urchins and fish. For baseline also sampling for determination of weight, age, epiphytes is performed. Sampling sites cover a wide degree of wind exposure gradient.

Ecosystem Based Monitoring (EBM) (Henning Steen)

Effect of kelp harvest on ecosystem services and kelp associated organisms (extent, magnitude duration reversibility) has not been fully identified in Norway, although fish and crab studies are performed, and is assessed to require further studies.

Fish studies methodology includes time lapse camera (remote underwater video (BRUV), however, fish catch using common fishing gear may give an integrated presence of fish in the kelp forest over day.

Editorial note

Since the workshop, following papers have been published that elucidate some of the above mentioned effects:

H. Steen, F.E. Moy, T. Bodvin and V. Husa. 2016. Regrowth after kelp harvesting in Nord-Trøndelag, Norway. ICES Journal of Marine Science, 73: 2708–2720. https://doi.org/10.1093/icesjms/fsw130.

K. M. Norderhaug, K. Filbee-Dexter, C. Freitas, S.-R. Birkely, L. Christensen, I. Mellerud, J. Thormar, T. van Son, F. Moy, M. Vázquez Alonso, H. Steen. 2020. Ecosystem-level effects of large-scale disturbance in kelp forests. Marine Ecology Progress Series. https://doi.org/10.3354/meps13426.

T.C. van Son, N. Nikolioudakis, H. Steen, J. Albretsen, B. Rugaard Furevik, S. Elvenes, F. Moy, K.M. Norderhaug. 2020. Achieving reliable estimates of the spatial distribution of kelp biomass. Front Mar Sci 7:107. https://doi.org/10.3389/fmars.2020.00107.

Literature review (Ole Geertz-Hansen)

Management, including harvest strategy, methodology and yield, of the resource should be considered and aligned with a principle of sustainability. "Sustainability" may be interpreted as: 1) Maximum sustainable yield (MSY), or 2) Ecosystem based management (EBM). However, knowledge of the extend of the resources as well as the harvest yield it potential may sustain is as important for coming harvesters as the environmental impact, including cascade/side effects is important for other ecosystem services. Baseline will give input to decisions on harvest strategy: clear cut, strip cut or "pluk hugst", which, again may depend on species (e.g., cut of *Ascophyllum nodosum* compared to harvest by rake sledge of *Laminaria hyperborea*).

Harvest impact on seaweed community in Greenland according to harvest strategy may be influenced by complex topography of sea bed in Greenland, and the mixed species kelp communities. However, will harvest result in change in kelp community structure towards a shift in species dominance? It is assessed that more studies are needed.

Regarding regulation and socioeconomics, the bottlenecks in Greenland are identified to be, e.g., lack of tradition for commercial harvest, lack of tradition for industry innovation, and that jurisdiction and legislation is not fully developed. One man companies require a suite of skills.

The participants agreed on that a monitoring programme should accommodate a sustainability principle approach that secures other ecosystem services. This includes a baseline including all trophic levels and management of the resource towards not only MSY but also minimizing cascade effects.

3.1.3 Harvest optimization in Greenland

Seaweed harvesting in Greenland (Ulrik Lyberth)

One one-man seaweed harvest company is active in Greenland; MAKI Seaweed Greenland by Ulrik Lyberth in the Sisimiut area.

Fucus vesiculosus and *Saccharina latissima* (stipe and lamina) is the primary product sources.

Mitigation considerations to make seaweed harvesting in the Sisimiut area sustainable are:

- Collection of drift seaweed from storms
- Harvesting by a three split anchor and not trawl or sledge
- Drying of seaweed by air, no use of energy.

The experience of distributing seaweed products in Greenland shows a surprisingly larger proportion of sale to the settlements compared to the villages.

It is assessed that the domestic market is saturated by the products of MAKI Seaweed Greenland, and the vision is to expand abroad.

Drying of seaweed in Greenland is easy due to the dry air. However, large amounts of seaweed are labour demanding, which challenge is sought to be met by assistance from settlement inhabitants, although the interest is limited and administration comprehensive.

Administrative procedures are, in general, challenging. According to the veterinarian authorities, the company shall develop a self-control programme for cleaning of facilities for each species production. All procedures connected with, e.g., harvest license, quality assurance and export are long lasting and troublesome, which is exaggerated by constant exchange of case officers.

Commercialisation and investment in Greenland seaweed industry (Klaus Berg)

Initiatives on seaweed exploitation and production in Greenland were in order to support the economies in the Greenland settlements. Therefore, production companies in Rode Bay, Disko Bay, (Rode Bay Fish) and in Denmark were established to reach international markets.

It is acknowledged that there are areas in Greenland that may be more or less rich in seaweed stocks. Therefore, expert knowledge is important for localising and mapping the resource in a specific area before further initiatives regarding production are taken.

It was the vision to keep the refinement of seaweed products in Greenland to obtain most value for Greenland regarding jobs and economy. However, self-financing and engagement from the locals were limited.

A meeting was held in Ilulissat in 2015 for promoting Greenland seaweed products, however, it was not followed up by local production, and delivery assurance was insufficient. Furthermore, economical investment was checked by lack of consistency in permits from the authorities.

In general, synchrony between production and purchaser has not been established as well as role by authorities and investment.

The initiative is supported with respect to product development and quality assurance by professor Ole Mouritsen, University of Southern Denmark, and Dansk Supermarked Group. Development of seaweed mats for export to Asia was accomplished, but was not followed up upon. Royal Greenland, which has channels for sale available, has been interested but has yet not invested.

3.2 Outcome

In accordance with the workshop programme (Annex I) and based on the participants' presentations following were developed:

- Outline for a baseline and monitoring programme for seaweed harvest in Greenland (Chapter 4)
- Recommendations for development of a seaweed industry in Greenland (Chapter 5)
- A list of identified knowledge gaps regarding a sustainable seaweed harvest in Greenland (Chapter 6).

4 Baseline and monitoring programme outline for Greenland

Susse Wegeberg, Ole Geertz-Hansen, Kjersti Sjøtun, Henning Steen, Ulrik Lyberth & Klaus Berg

The monitoring programme should accommodate two different approaches for:

1) Baseline and standing stock estimates
2) Actual monitoring for potential effects of harvest and regulation development and adaptation

For the monitoring program, following assumptions and expectations are taken for basis:

- Development of the industry is bottom-up, i.e., from small scale with a potential development in the industry towards larger scale:
- Small scale of one-man companies with a harvest of 2.5-3 t per year
- Medium scale of small companies with subcontractors of seaweed harvest
- Large scale harvest / sales of larger companies, which also will take delivery of harvest from smaller companies corresponding to the fish industry in Greenland

The monitoring programme outline is hence drafted in steps from a monitoring minimum (registration of harvest amounts) to monitoring for assurance of seaweed community sustainability.

4.1 Baseline and standing stock estimates

Basic knowledge on distribution (vertical and geographical) and size of resource (species specific) as well as renewability (regrowth) is needed.

4.1.1 Distribution of resource; vertically and geographically

Based on existing underwater video transect along the Greenland west (85) and east coast (260), the geographical distribution of species and kelp coverage can be estimated and homogenous regions identified for further investigation. From these homogenous regions representative areas can be selected for further standing stock and regrowth investigations can be selected. However, focus should be on areas close to settlements and villages.

Large scale standing stock estimates

A rough estimate of kelp forest can be calculated from mean biomass of kelp (species) per area (m^2) in relation to depth and substrate type.

Mean biomass can include integration/mean of biomasses from different depth and wind fetch.

A more complicated and precise mapping may include modelling of biomass with depth and wind fetch calibrated with ground-truthing.

Area within depth of mean biomass and suitable substrate multiplied with mean biomass gives an estimate for standing stock in a specific region.

Calculating standing stock from above method requires depth and substrate data.

A more precise estimate can be calculated if height of vegetation data can be obtained and is calibrated with weight.. This has been done in Norway with *Laminaria hyperborea*, however, the height of the kelp vegetation in Greenland may be more difficult due to mixed species and trailing vegetation.

Remote sensing of kelp covered areas by high resolution satellite images is under development in Greenland. However, this may at present only be possible until app. 20 m's depth and requires a light substratum of the seabed. Height of vegetation cannot be obtained from these images.

Side scan sonar or echo sounder (SMRAD ECCO 500) (multibeam) could be used in a grid to obtain distribution and height of vegetation, however, this method will not give information on density.

Estimates of tidal vegetation may be obtained from:

- Arial photos, however, tidal cycles must be considered to be sure that the photos are taken at low tide. Shadows from mountains may make interpretation difficult
- High resolution satellite images, where images from low tide time periods can be requested, and combined with ground-truthing data of biomass per area.

4.1.2. Regrowth and recolonization

Regrowth and recolonization are important for recommendations on number of years in harvest cycles.

Sea urchins and storms may impact on regrowth.

Regrowth is estimated for each commercial species by used of established methods: lamina and tip elongation, lamina length, internodia length in relation to number of bladders.

Recolonization is estimated from coverage, density and abundance per area, and eventually biomass. Recolonization of species is recorded continuously.

4.2 Monitoring programme outline

4.2.1. Questions to be answered by baseline and monitoring programme

Following questions, which results from a monitoring programme must be able to answer, were identified from brainstorm:

- At which harvest intensity level shall monitoring of re-growth be initiated?
- For development of regulation, how to :
  - Scope small vs. industrial harvest scale?
  - Select harvesting strategy; Harvesting field size – large areas (as in Norway) or smaller areas earmarked for seaweed harvest?
  - Identify protected (reserve) areas, which could be important as "special banks" to mediate large scale ecological effects?
  - Determine harvesting cycle (length of fallow period between harvests of the same area?

  - Kelp forest production estimations?
  - Re-growth rate of kelp species?
  - Production of tidal zone seaweed species estimations?
  - Species specific re-growth potential?
  - Time for ecosystem restitution?
  - Establishment of correlation coefficient between size of plants and biomass for monitoring by underwater video cameras?

Monitoring requirements:

- Baseline data and reference (no-take) areas are important for detecting effects
- Harvester landing reports/diaries would be valuable for monitoring outtake and for sustainability studies:
  - Harvesting date, location, method, weight (per species) etc.
- Underwater video monitoring for studying regrowth and sea urchin abundance (frequency would depend on harvesting cycle)
- Harvesting trials in smaller areas may be used to study ecological effects (including fish)

4.2.2 Monitoring programme components

Seaweed:

Diversity
Coverage
Biomass
Production
Regrowth
Age

Associated fauna, key species identified from baseline of

Invertebrates, e.g., *Caprella, Gammarus, Gammarellus, Littorina,*
Fish, habitat users, e.g., capelin, lumpsucker, sea scorpion
Fish, predators of grazers, e.g., cod and catfish

Grazers for cumulative impacts:

Sea urchins

4.2.3 Monitoring methods, proposals

Kelp forest

- Logging of temperature, salinity and light
- Use of video for kelp coverage, composition and abundance of sea urchins
  - Scale necessary, use of laser pointers?
- Methodology for use of video as monitoring instrument need development with respect to quantitative metrics for seaweed biomass/succession, establishment of size classes?
  - Number of stations?
  - Camera type

    - Establishment of correlations between video data and true metric data (biomass), including establishment of correlation between size of plants and biomass
    - Diversity from video must be calibrated with samples

- Fauna traps placed in kelp forests for monitoring associated fauna (Steen et al. 2016), potentially in combination with net catch around kelp plants

- Fish studies methodology
    - time lapse camera (optimal 3 m over kelp forest)
        - No camera sight in kelp forest
        - Fish presence difficult to integrated over time – time without fish and time with many fish
        - No size and weight obtained but size classes can be registered and be correlated to weight
    - Baited remote underwater video (BRUV) can be used for qualitative data for fish diversity in kelp forest, could be combined with conventional fish catch
    - Fish catch using conventional fishing gear may give an integrated presence of fish in the kelp forest over day
        - The right placement of GRN in the kelp forest for representative catch

Tidal zone

Study quadrants are established in reference area and in harvest area.

These established quadrants are being followed for a year series to map succession after harvest.

This method includes coastal community diversity, coverage, biomass, abundance.

4.2.4 Monitoring programme outline

Hereby follows an outline of a potential monitoring programme. The monitoring intensity increases subsequently to meet potential increasing harvest intensity.

Small to medium scale harvest intensity

1) Identification of homogenous regions of kelp forest from existing underwater videos and tidal community from existing data

2) Designation of reference areas – harvest free areas – for reference and research

3) Standing stock estimates

4) Production and estimates of biomass renewability

5) Registration of site specific harvest amounts, harvest method, sea urchins, etc.

Medio to industrial scale harvest intensity

6) Mapping of impact on ecosystem, including associated fauna, fish and seabird

7) Recolonization rate estimates

8) Identification and monitoring of other stressors influencing recolonization rate, e.g., sea urchins

9) Regulation based on recommendation on harvest strategy and harvest cycles

10) Monitoring reference and harvest areas with respect to above described monitoring components.

5. Knowledge transfer from Acadian Seaplants, Nova Scotia, Canada.

Susse Wegeberg & Ole Geertz-Hansen

Proceedings and knowledge transfer from visiting Acadian Seaplants Ltd (ASL) in Nova Scotia[1].

ASL is a company with three commercial "legs":

1) Extract from *Ascophyllum nodosum* for biostimulant products in Cornwallis

2) Dried and milled *Ascophyllum* (and *Fucus vesiculosus*) for animal feed in Yarmouth

3) Cultivation of *Chondrus crispus* for Hana-Tsunomata™ in Charlesville

ASL employs about 600 persons in Nova Scotia, New Brunswick, Ireland and Scotland, and is a $ 100 million business.

The visit was organised through Dr Raul Ugarte, Resource Scientist, who took his time, with his team, to show us the three ASL plants as well as harvesting. Further, Raul organised a meeting for us with the regulative body for seaweed harvesting in Nova Scotia, Wendy Vissers. We also included a workshop where Greenland seaweed vegetation and status for harvesting was presented by us, and where Raul presented seaweed stock evaluation methodologies in more details.

5.1 Seaweed extract plant and the James S Craigie research Centre in Cornwallis

In Cornwallis, the extraction plant, the Deveau Center, (Figure 5.1) is located. Here extractions of *Ascopyllum nodosum* is used for a biostimulant product for agriculture.

Figure 5.1. Acadian Seaplants Ltd's Deveau Center for research in and production of biostimulants from *Ascophyllum nodosum* extraction.

In the associated research centre, The James S Craigie Research Center, evaluation of the effects of applying the biostimulant product are performed as well as maintenance of seed stock of a number of red, brown and green seaweed species.

The research in the centre is organised in a number of programmes, one of which is a seeding programme: maintenance of seed stock of particular *Chondrus crispus*, but also other red, brown and green seaweed species, clone selection.

[1] As an editorial disclaimer, all information is stated as given at the visits and has not as such been verified from other sources.

5.2 Yarmouth processing plant

The Yarmouth processing plant is for milling of dried primarily *A. nodosum*, but also *Fucus vesiculosus* is processed.

The harvested seaweed biomass is dried on an old air strip (Fig. 5.2) for about one day in a thin layer; it is spread using a manure spreader, collected and chopped by a hay harvester. Bulldozers are used for handling the biomasses on the airstrip. When laid out for drying, a seagull scarecrow is used to keep the birds away from the biomass.

Figure 5.2. Drying of fucoid biomass on an old airstrip.

After air drying, the biomass is entering a further drying process. The dried seaweed biomass is milled into different qualities/fineness.

The milled product is bought by fodder companies, which have their own formulas for the fodder blend.

5.3 Harvest at Clark's Harbour

We visited Clark's Habour at low tide to go out with boat to see *Ascophyllum* harvest. The specialised, and by ASL developed, harvester rake (Figure 5.3) was demonstrated, and the potential harvest by a trained harvester was a full seaweed dingy (5-6 tonnes) within an hour. The dingy is specialised for seaweed harvest in being very shallow and broad (Figure 5.4).

Figure 5.3. Seaweed harvester rake used by harvesters providing seaweed biomass for Acadian Seaplants Ltd.

Figure 5.4. Full seaweed dingy specialised by being shallow and broad.

5.4 On land cultivation facilities at Charlesville

ALS produces dried *Chondrus crispus* in three colours; red, yellow and green, the Hana-Tsunomata™ product. It is produced from cultivated *C. crispus*.

ALS's cultivation and processing facilities for *Chondrus crispus* are located in Charlesville, southeast of Yarmouth. The cultivation facilities includes up-scaling laboratory and "greenhouses" for the culture initiated in Cornwallis in the James S Craigie Research Centre (see above).

We were visiting the facilities and were expected by Allan Archibald, the site manager, and after a short introduction to the facilities, product and history of the production, Allan took us on a guided tour.

5.4.1 History

The facilities were started in 1978 on marine colloids from *Chondrus crispus*, the llamda carrageenan, which is obtained from the diploids stage, the sporophyte, of the species (the less valuable kappa carrageenan is obtained from the haploid stage, the gametophyte). However, the sale of this colloid production went down, and 20 years ago, the production of the Hana-Tsunomata™, the tricolour *Chondrus* (Figure 5.5), was initiated and became a huge success as sales product for Japan.

Figure 5.5. The three colours of *Chondrus crispus* which constitute the Hana-Tsunomata™ product from Acadian Seaplant Ltd for the Japan market.

5.4.2 Up-scaling in open-air cultivation

Chondrus crispus biomass was up-scaled in raceways with aerated seawater at Charlesville, Nova Scotia, Canada (Figure 5.6).

Biomass is harvested from the raceways simultaneously, and processed on site for the final product.

Figure 5.6. Raceways with aerated seawater for *Chondrus crispus* cultivation by Acadian Seaplants Ltd at Charlesville, Nova Scotia, Canada.

5.5 Regulation of seaweed harvest in Nova Scotia, Department for Fisheries and Aquaculture

The Department for Fisheries and Aquaculture of the province Nova Scotia is located in Cornwallis, and on Friday 31st May 2019, we met with Wendy Vissers, who is biologist and resource advisor of Marine Plants for information regarding seaweed harvest regulation in Canada and Nova Scotia. The information below is based on our meeting with Wendy Vissers, but also information from Raul Ugarte has been included.

Please find the official documents with regard to regulation, including Ocean's Act here:

https://nslegislature.ca/sites/default/files/legc/statutes/fisheries%20and%20coastal%20resources.pdf

(Section VI, page 30)

Regulations: https://www.novascotia.ca/just/regulations/regs/fcrweed.htm

Leasing application and protocol for stock assessment as Appendix 4.

With respect to sale of seaweed for human consumption, this is regulated by the Canadian Food Inspection Agency. A certificate has been developed for hum consumption seaweed products to go for export, while domestic sales do not need certificate.

The harvest regulation is developed and implemented by the provinces in Canada, whereas the tidal zone belongs to the provinces, but the subtidal is federal.

In Nova Scotia, the kelp forest cannot be harvested due to being a nursing ground for lobsters. Catching lobsters are among the biggest industry in Nova Scotia.

Scotland applies the same system as in Canada, while in Ireland, no regulation as such has been established, but is based on traditions, although area conservation is a subject of both political and public importance.

5.5.1 Leases

Nova Scotia is the only province with a lease system. The province can grant leases, which are defined by harvest potential for a meaningful outcome for the harvesters and companies. When the companies apply, they may suggest the outline of the lease.

Application for leases shall be followed by a business plan and a resource management plan.

The application for lease(s) is followed by a public hearing, and the applicant must inform the public.

For small scale operators / lease holders funding can be provided for provincial stock assessment. They can be granted "option to lease", which means that the lease is put on hold, and then they have 6 months to do the stock assessment where after lease may be issued.

The lease is granted for max. 15 years; initially for 2-3 years, and if lease resource is well-managed and found in good condition, the lease is granted up to 15 years.

If no harvesting activities, the lease must be handed back after 5 years.

Harvest available resource is estimated by applicant but assessed by 3rd party.

The lease holder has the ultimate response for the lease stock and hence the activities of the harvesters. When harvesting outside leases, the harvesters are responsible for sticking to regulation. The harvesters need a permit for harvesting and a harvester ID.

Only hand-harvesting is allowed.

The leases are divided into a number of sectors to spread harvesting along the lease. Each sector has its own harvest quota.

5.5.2 Lease price and royalties

Lease fee is CAN 663 per year + CAN 2.45 per tonnes wet weight. The first 270 tonnes are royalty free, which means that for every tonne harvest up to 270, the royalty per tonne reduces the annual fee:

CAN 663 – 2.45 x tonnes landed

Fees and royalties are paid to the Province.

5.5.3 Harvest regulation

For evaluation of stock and impact on seaweed community, also at high tide where fish may be present, an EIA shall be developed for the harvesting activities and amount of landings per sector. For ASL, the EIA was developed over 5 years and included studies on regrowth, use of habitat etc.

In Nova Scotia, and in the leases of ASL, the sustainable harvest limit is estimated to 40% on a scientific basis. However, the threshold limit for harvest is a conservative 20%. If the areas are very well-monitored, the harvest limit may go up to 25%.

In New Brunswick, the harvest threshold limit is max 17% of stock based on estimation of regrowth from a total cleared area.

5.5.4 Stock and harvest evaluation

To evaluate the harvest percentage of stock for sustainable harvest, the amount of standing stock and regrowth must be established.

From aerial photos at low tide the area with seaweed vegetation is estimated (this area seems not to change much over time) followed by ground-truthing by random sampling in the mid tidal zone, the standing stock is estimated.

Length and weight of plants as well as density (number of plants) per m^2 are established by using 50 × 50 cm squares. 0.25 m^2 is found to be the right size in terms of labour and minimising edge-effects. If squares are too small, like 25 × 25 cm, the effect from relative long edge in relation to area is found to give a stock overestimation of 30%.

Plants are measured from hold-fast to "bush"-length. Including the longest shoots may give an overestimation of the total stock. When cut for biomass estimation, 10 cm are left for regrowth, and are not considered to be significant in the total biomass estimation.

For southwest Nova Scotia, the biomass is 10-11 kg per m^2. It is considered, that at biomasses < 6 kg per m^2, harvesting is not durable.

5.5.5 Monitoring and reporting

Every year, the total amount of landings must be reported.

Monitoring of sectors is performed after "fruiting" season (after June in Nova Scotia). Biomass lost to fruiting is estimated to be 5%. The monitoring includes:

- Visual inspection for observation of damage of the stock from natural events such as ice scouring, and which may alter the sustainable harvest amount.
- Biomass estimations to assess if vegetation biomass is stable (June-September), and which is performed every year if sector is harvested

Audition is part of the seaweed harvest regulation.

6 Seaweed industry development in Greenland, recommendations

Susse Wegeberg, Kjersti Sjøtun, Henning Steen, Klaus Berg, Ulrik Lyberth & Ole Geertz-Hansen

At present, the estimate of standing stock of seaweed and regrowth rate is not estimated. A preliminary study has been performed in the Qaqortoq area (Wegeberg et al. 2005, Wegeberg 2007), however, more detailed studies are needed according to Chapter 5. Therefore, we operate only with small, medium to industrial scale in this report without designated the harvesting amount limits for these harvest scale classification. As the business may develop and the baseline studies have been accomplished, more accurate amounts can be designated to delimitate the scale classification.

Except from the lack in knowledge regarding standing stock and harvesting potential, which knowledge may serve to promote the business, it is assessed that, at present, there is a number of administrative bottlenecks and barriers to bring the business of seaweed harvest forward in Greenland.

These bottlenecks and barriers are identified as:

It seems that seaweed harvesting is not anchored within the authorities and hence the application for seaweed harvest, sale of products and export procedure and requirements are not clear. It results in that the process is very effort demanding and time consuming for the applicant.

Application for seaweed harvest, sale of products and export are at present to several authorities, which may make the application process unnecessary complicated.

Internal control programme has presently to be developed and approved by the authorities for each product type (species), although the product processes are similar.

Organisations that have been established to support and enhance business development in Greenland seem not geared to support seaweed harvesters as well as development and marketing of seaweed products.

Requirements to dry seaweed are at present considered to be unnecessary high, which lead to drying of seaweed a bottleneck in the production phase.

It is recommended that:

One door principle for approval procedures regarding harvest licenses, quality assurance and self-control, export, including advice panel on biology and harvest methodology development

Clarification and settlement of jurisdiction and development of legislation for harvest licenses and seaweed export

Reconsideration of requirements for drying of seaweed, as natural drying conditions (sun, wind) give best quality of the products, while at the same time, necessary veterinary requirements are met.

Simplification of internal control procedure for product types with same process.

7 Knowledge gaps

Susse Wegeberg, Kjersti Sjøtun, Henning Steen, Klaus Berg, Ulrik Lyberth & Ole Geertz-Hansen

Following knowledge gaps regarding a sustainable harvest of seaweeds in Greenland were identified by the work-shop participants who possessed expertise/experience in seaweed biology and ecology, harvest, drying and sale as well as marketing/innovation:

1) Identification of regions with homogenous kelp vegetation
2) Standing stock estimates for regions
3) Regrowth estimates for different climatic regimes
4) Holistic surveys of kelp forest to identify impacts from harvest and potential cascade effect
    a. Kelp production as carbon source for food webs
    b. Invertebrates
    c. Fish – diversity, abundance, stomach content for food web mapping
    d. Birds
5) Sea urchins as contributor to cumulative impacts
    - It is assessed that the upper vertical limit for sea urchins is determined by temperature and salinity in Norway (Husa et al. 2014). Logging of salinity and temperature has been initiated together with a characterization of the vertical distribution of sea urchins in Kobbefjord, Nuuk.
6) Recolonization

7) Harvest strategy and methodology
8) Drying methodology
9) Cultivation techniques as alternative to harvest
   - For single species harvest as the kelp forest in Greenland often is mixed by several kelp species, and for more homogeneous and optimal quality
10) Review of requirements for export of seaweed products world wide
11) Markets survey of Greenland seaweed products; Greenland brand/narrative/product presentation and design
12) Certificates requirements of Greenland seaweed products (Ø, MSC)

8 References

Armitage CS, Husa V, Petelenz-Kurdziel EA, Sjøtun K (2017) Growth and competition in a warmer ocean: a field experiment with a non-native and two native habitat-building seaweeds. Mar Ecol Prog Ser 573:85-99. https://doi.org/10.3354/meps12161.

Bailey E, Owen K. 2014. Seaweed harvesting. Natural England's Advice. https://www.westgateonsea.gov.uk/shared/attachments.asp?f=ffe10000%2D2ad4%2D4f3e%2D90f1%2D2e1e8e3e8103%2Epdf&o=Algae%2Dharvesting%2DNE%2DSeaweed%2DHarvesting%2DAdvice%2D2014%2Epdf.

Christie H., Fredriksen S., Rinde E. (1998) Regrowth of kelp and colonization of epiphyte and fauna community after kelp trawling at the coast of Norway. In: Baden S., Phil L., Rosenberg R., Strömberg JO., Svane I., Tiselius P. (eds) Recruitment, Colonization and Physical-Chemical Forcing in Marine Biological Systems. Developments in Hydrobiology, vol 132. Springer, Dordrecht. https://doi.org/10.1007/978-94-017-2864-5_4

Christie H, Jørgensen NM, Norderhaug KM, Waage-Nielsen E. 2003. Species distribution and habitat exploitation of fauna associated with kelp (Laminaria hyperborea) along the Norwegian coast. Journal of Marine Association, UK 83: 687-699.

Christie H, Norderhaug, KM, Fredriksen S. 2009. Macrophytes as habitat for fauna. Marine Ecology Progress Series 396: 221-233.

Dunningham, J. & Atack, T. 2012. Management of the UK macroalgae industry. Viking Fish Farms Ltd. NETALGAE. Available online www.netalgae.eu.

Dunton KH, Schell DM. 1987. Dependence of consumers on macroalgal (*Laminaria solidungula*) carbon in an arctic kelp community: _13C evidence. Mar Biol 93: 615-625.

Estes JA, Tinker MT, Williams TM, Doak DF. 1998. Killer Whale Predation on Sea Otters Linking Oceanic and Nearshore Ecosystems. Science 282: 473-476. DOI: 10.1126/science.282.5388.473

Fredriksen S. 2003. Food web studies in a Norwegian kelp forest based on stable isotope (_13C and _15C) analysis. Marine Ecology Progress Series 260: 71-81.

Garbary DJ, Galway ME, Halat L. 2017. Response to Ugarte et al.: Ascophyllum (Phaeophyceae) annually contributes over 100% of its vegetative biomass to detritus. Phycologia, 56:1, 116-118, DOI: 10.2216/16-44.1.

Guiry M.D. & Morrison L. 2013. The sustainable harvesting of Ascophyllum nodosum (Fucaceae, Phaeophyceae) in Ireland, with notes on the collection and use of some other brown algae. Journal of Applied Phycology 25: 1823–1830.

González A, Beltrán J, Hiriart-Bertrand L, Flores V, de Reviers B, Correa JA, Santelices B. 2012. Identification of cryptic species in the Lessonoa nigrescens comples (Phaeophyceae, Laminariales). Journal of Phycology 48: 1153-1165. doi:10.1111/j.1529-8817.2012.01200.x

González, A.V., Borras-Chavez, R., Beltrán, J. et al. Morphological, ultrastructural, and genetic characterization of coalescence in the intertidal and shallow subtidal kelps Lessonia spicata and L. berteroana (Laminariales, Heterokontophyta). J Appl Phycol 26, 1107–1113 (2014). https://doi.org/10.1007/s10811-013-0112-6

Halat L., Galway M.E., Gitto S. & Garbary D.J. 2015. Epidermal shedding in Ascophyllum nodosum (Phaeophyceae): seasonality, productivity and relationship to harvesting. Phycologia 54: 599–608

Husa V, Steen H, Sjøtun K. 2014. Historical changes in macroalgal communities in Hardangerfjord (Norway), Marine Biology Research, 10: 226-240. DOI: 10.1080/17451000.2013.810751

Kelly, E. (ed.). 2005. The role of kelp in the marine environment. Irish Wildlife Manuals, No. 17. National Parks and Wildlife Service, Department of Environment, Heritage and Local Government, Dublin, Ireland.

Kelly, L., Collier, L., Costello, M. J., Diver, M., McGarvey, S., Kraan, S., Morrissey, J. & Guiry, M. D., "Impact Assessment of Hand and Mechanical Harvesting of *Ascophyllum nodosum* on Regeneration and Biodiversity", Marine Resource Series, Marine Institute 2001.

Krause-Jensen D, Marbà N, Olesen B, Sejr MK, Christensen PB, Rodrigues J, Renaud PE, Balsby TJS, Rysgaard S. 2012. Seasonal sea ice cover as principal driver of spatial and temporal variation in depth extension and annual production of kelp in Greenland. Global Change Biology 18: 2981- 2994. DOI: 10.1111/j.1365-2486.2012.02765.x

Levitt GJ, Anderson RJ, Boothroyd CJT, Kemp FA. 2002. The effects of kelp harvesting on its regrowth and the understorey benthic community at Danger Point, South Africa, and a new method of harvesting kelp fronds. S. Afr. J. mar. Sci. 24: 71–85.

Lippert H, Iken K, Rachor E, Wiencke C. 2001. Macrofauna associated with macroalgae in the Kongsfjord (Spitsbergen). Polar Biol 24: 512-522.

Lorentsen S-H, Sjøtun K, Grémillet D. 2010. Multi-trophic consequences of kelp harvest. Biological Conservation 143: 2054-2062.doi.org/10.1016/j.biocon.2010.05.013.

MacMonagail M, Cornish L, Morrison L, Ajaújo R, Critchley AT. 2017. Sustainable harvesting of wild seaweed resources. European Journal of Phycology 52: 371-390.

Meland M, Rebours C. 2012. Short description of the Norwegian seaweed industry. Bioforsk FOKUS 7(2):278-279.

Norderhaug KM, Christie H. 2009. Sea urchin grazing and kelp re-vegetation in the NE Atlantic, Marine Biology Research, 5:6, 515-528, DOI: 10.1080/17451000902932985

Norderhaug KM, Christie H, Fosså JH, Fredriksen S. 2005. Fish-macrofauna interactions in a kelp (Laminaria hyperborea) forest. J Mar Ass UK 85: 1279-1286.

K. M. Norderhaug, K. Filbee-Dexter, C. Freitas, S.-R. Birkely, L. Christensen, I. Mellerud, J. Thormar, T. van Son, F. Moy, M. Vázquez Alonso, H. Steen. 2020. Ecosystem-level effects of large-scale disturbance in kelp forests. Marine Ecology Progress Series. https://doi.org/10.3354/meps13426.

Renaud PE, Løkken TS, Jørgensen LL, Berge J, Johnson BJ. 2015. Macroalgal detritus and food-web subsidies along an Arctic fjord depth-gradient. Frontiers in Marine Science 2. 31 pp. DOI=10.3389/fmars.2015.00031.

Rothman MD, Anderson RJ, Smit AJ. 2006. The effects of harvesting of the South African kelp (Ecklonia maxima) on kelp population structure, growth rate and recruitment. In: Anderson R., Brodie J., Onsøyen E., Critchley A.T. (eds) Eighteenth International Seaweed Symposium. Developments in Applied Phycology, vol 1. Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-5670-3_14

Seeley RH, Schlesinger WH. 2012. Sustainable seaweed cutting? The rockweed (Ascophyllum nodosum) industry of Maine and the Maritime Provinces. Annals of the New York Academy of Sciences 1249: 84–103.

Sharp G.J., Ugarte R. & Semple R. 2006. The ecological impact of marine plant harvesting in the Canadian Maritimes, implications for coastal zone management. ScienceAsia 32 (Supplement 1): 77–86.

Steen H, Bodvin , Moy FE, Sannæs H, Hansen Hø. 2015. Undersøkelser av stortarehøsting i Nordland i 2015/Studies of kelp harvesting in Nordland in 2015. Rapport fra Havforskningen 26-2015.

Steen H, Moy FE, Bodvin T, Husa V. 2016. Regrowth after kelp harvesting in Nord-Trøndelag, Norway. ICES Journal of Marine Science, 73: 2708–2720. https://doi.org/10.1093/icesjms/fsw130.

Ugarte, R.A. An evaluation of the mortality of the brown seaweed Ascophyllum nodosum (L.) Le Jol. produced by cutter rake harvests in southern New Brunswick, Canada. Journal of Applied Phycology 23: 401–407. https://doi.org/10.1007/s10811-010-9574-y.

Ugarte R, Sharp G. 2001. A new approach to seaweed management in Eastern Canada: the case of *S*. Cah. Biol. Mar 42: 63-70.

Ugarte R. & Sharp G. 2012. Management and production of the brown alga Ascophyllum nodosum in the Canadian Maritimes. Journal of Applied Phycology 24: 409–416.

Ugarte RA, Sharp G, Moore B. 2006. Changes in the brown seaweed Ascophyllum nodosum (L.) Le Jol. plant morphology and biomass produced by cutter rake harvests in southern New Brunswick, Canada. In: Anderson R., Brodie J., Onsøyen E., Critchley A.T. (eds) Eighteenth International Seaweed Symposium. Developments in Applied Phycology, vol 1. Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-5670-3_16

Ugarte R, Lauzon-Guay J-S, Critchley AT. 2017. Comments on Halat L., Galway M.E., Gitto S. & Garbary D.J. 2015. Epidermal shedding in *Ascophyllum nodosum* (Phaeophyceae): seasonality, productivity and relationship to harvesting. Phycologia 54(6): 599–608., Phycologia, 56:1, 114-115, DOI: 10.2216/16-36.1.

Vadas R.L., Wright W.A. & Beal B.F. 2004. Biomass and productivity of intertidal rockweeds (Ascophyllum nodosum LeJolis) in Cobscook Bay. Northeastern Naturalist 11: 123–142.

Vandermeulen H. 2013. Information to support assessment of stock status of commercially harvested species of marine plants in Nova Scotia: Irish moss, rockweed and kelp. DFO Canadian Science Advisory Secretariat. Research Document 2013/042. 50 pp.

van Son TC, Nikolioudakis N, Steen H, Albretsen J, Rugaard Furevik B, Elvenes S, Moy F, Norderhaug KM. 2020. Achieving reliable estimates of the spatial distribution of kelp biomass. Front Mar Sci 7:107. https://doi.org/10.3389/fmars.2020.00107.

Vasquez J. 2008 Production, use and fate of chilean brown seaweeds: resources for a sustainable fishery. Journal of Applied Phycology 20: 457-467. 10.1007/s10811-007-9308-y

Vásquez JA, Westermeier R. 1993. Limiting factors in optimizing seaweed yield in Chile. Hydrobiologia 260/261:180–187

Vásquez JA, Piaget N, Vega JMA. 2012. The *Lessonia nigrescens* fishery in northern Chile: "how you harvest is more important than how much you harvest". Journal of Applied Phycology 24: 417–426. https://doi.org/10.1007/s10811-012-9794-4.

Vea J, Ask E. 2011. Creating a sustainable commercial harvest of Laminaria hyperborea, in Norway. Journal of Applied Phycology 23: 489–494. https://doi.org/10.1007/s10811-010-9610-y

Vega JMA, Broitman BR, Vásquez, JA. 2014. Monitoring the sustainability of Lessonia nigrescens (Laminariales, Phaeophyceae) in northern Chile under strong harvest pressure. J Appl Phycol 26: 791–801. https://doi.org/10.1007/s10811-013-0167-4

Wegeberg S. 2007. Er tang en ny marin resource i Grønland. Vand & Jord 3: 117-120.

Wegeberg S, Bangsholt J, Dolmer P, Hertz O, Mortensen AM, Pedersen PM. 2005. Nordic Seaweed Project. Grønland. Resultat-status for 2004. Københavns Universitet. 22 pp.

Wegeberg S, 2016. Session 1: Tang som en marin-ressource i Arktis. In: proceedings from Polarforskningskonferencen, Aalborg, 3 - 4 December 2015.

Wlodarska-Kowalczuk M, Kuklinski P, Ronowicz M, Legezynska J, Gromisz S. 2009. Assessing species richness of macrofauna associated with macroalgae in arctic kelp forests (Hornsund, Svalbard). Polar Biol 32: 897-905.

Appendix 1: Workshop programme

Sustainable harvest of seaweed in Greenland (SUSHi) - Workshop in Sisimiut 13-15 June 2017

Programme			***Presenter***
Monday 12th June		Arrival	
Tuesday 13th June	09:00	Welcome and introduction; project report outline	Ole Geertz-Hansen
	09:30	Seaweeds of Greenland; species, distribution and biomasses	Susse Wegeberg
	10:15	Status for seaweed harvest (and cultivation) in Greenland; innovation and public regulation	Ole Geertz-Hansen
	10:45	Discussion of harvest potential and monitoring issues	
	11:15	Development of monitoring programme in Norway; study basis	Kjersti Sjøtun
	12:00	Lunch	
	12:30	Kelp harvesting and monitoring in Norway	Steen Henning
	13:15	Presentation of literature review	Ole Geertz-Hansen
	13:45	Discussion of regulation and monitoring requirements in Norway and other relevant countries	
	14:30	Coffee	
	14:45	Seaweed harvesting in Greenland; mitigation considerations and quality requirements	Ulrik Lyberth
	15:30	Commercialisation and investments in Greenland seaweed industry; experience, possibilities and requirements for economic feasibility	Klaus Berg
	16:15	Discussion of harvest optimization needs in Greenland	
	16:45	Wrap up and allocation of tasks for Thursday	Ole Geertz-Hansen / Susse Wegeberg
	17:00	End of day	
Wednesday 14th June	09:00	Introduction to the Sisimiut area; seaweed harvesting areas	Ulrik Lyberth
	10:00 16.00	Sailing trip; underwater video and seaweed collection	Ulrik Lyberth / Ole Geertz-Hansen / Susse Wegeberg
	19:00	Workshop Dinner	
			Facilitator
Thursday 15th June	09:00	Introduction to the day	Ole Geertz-Hansen
	09:15	Session 1: Monitoring programme components - brainstorm	Kjersti Sjøtun
	10:15	Session 2: Monitoring programme outline	Susse Wegeberg
	11:15	Session 3: Monitoring programme components - description	Steen Henning
	12:15	Lunch	
	12:45	Session 4: Monitoring programme; feasibility	Ulrik Lyberth / Klaus Berg
	13:45	Session 5: Studies needed	Ole Geertz-Hansen
	14:45	Project proposal(s) development - outbreaks	Susse Wegeberg
	16:45	Wrap up	Ole Geertz-Hansen
	17:00	End of workshop	
Friday 16th June		Departure	