70th Annual Meeting of the European Federation of Animal Science

Animal Farming for a Healthy World

EAAP2019

Ghent – Belgium 26 – 30 August 2019

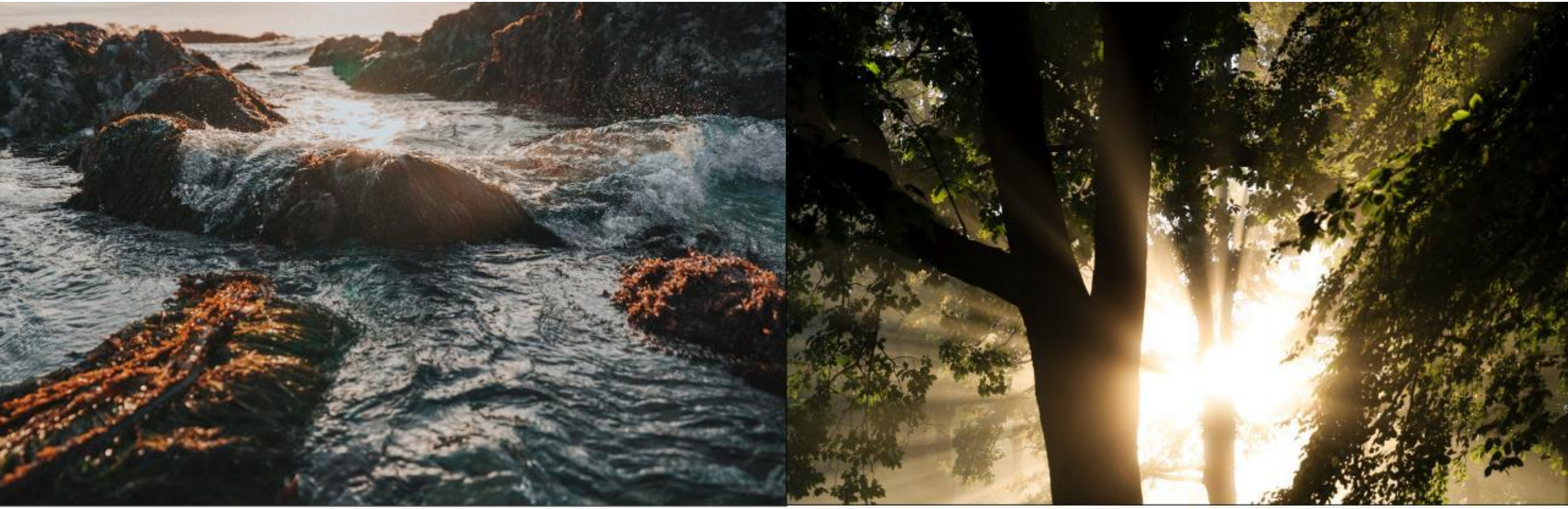
Seaweed as a feed resource for farmed animals

EAAP 2019, Ghent, Belgium, 27 August 2019

Margareth Øverland, Liv Torunn Mydland, Anders Skrede, Norwegian U. of Life Sciences

Outline

- Foods of Norway
- Food security
- Aquaculture and demand on feed
- Seaweed production in Norway in a global context
- Seaweed as a feed resource
  - a historical perspective
  - a glance at the literature
- Results from our research
- What's next?



FOODS OF NORWAY aims to feed fish and farm animals using sustainable new ingredients

Duration: 2015-2024 Finance: € 21.5 Million

FOODS OF NORWAY

sfi Centre for Research-based Innovation
The Research Council of Norway

Industrial partners

Borregaard
Felleskjøpet
AquaGen
Nortura
Viken Skog
Norsvin
denofa
Animalia
geno
Seaweed Energy Solutions AS
TINE
YARA
norilia
Pure nature refined

Supporting partners

Norsk Landbrukssamvirke
Norges Bondelag
NHO Mat og Drikke
Innovation Norway

New partner

BioMar

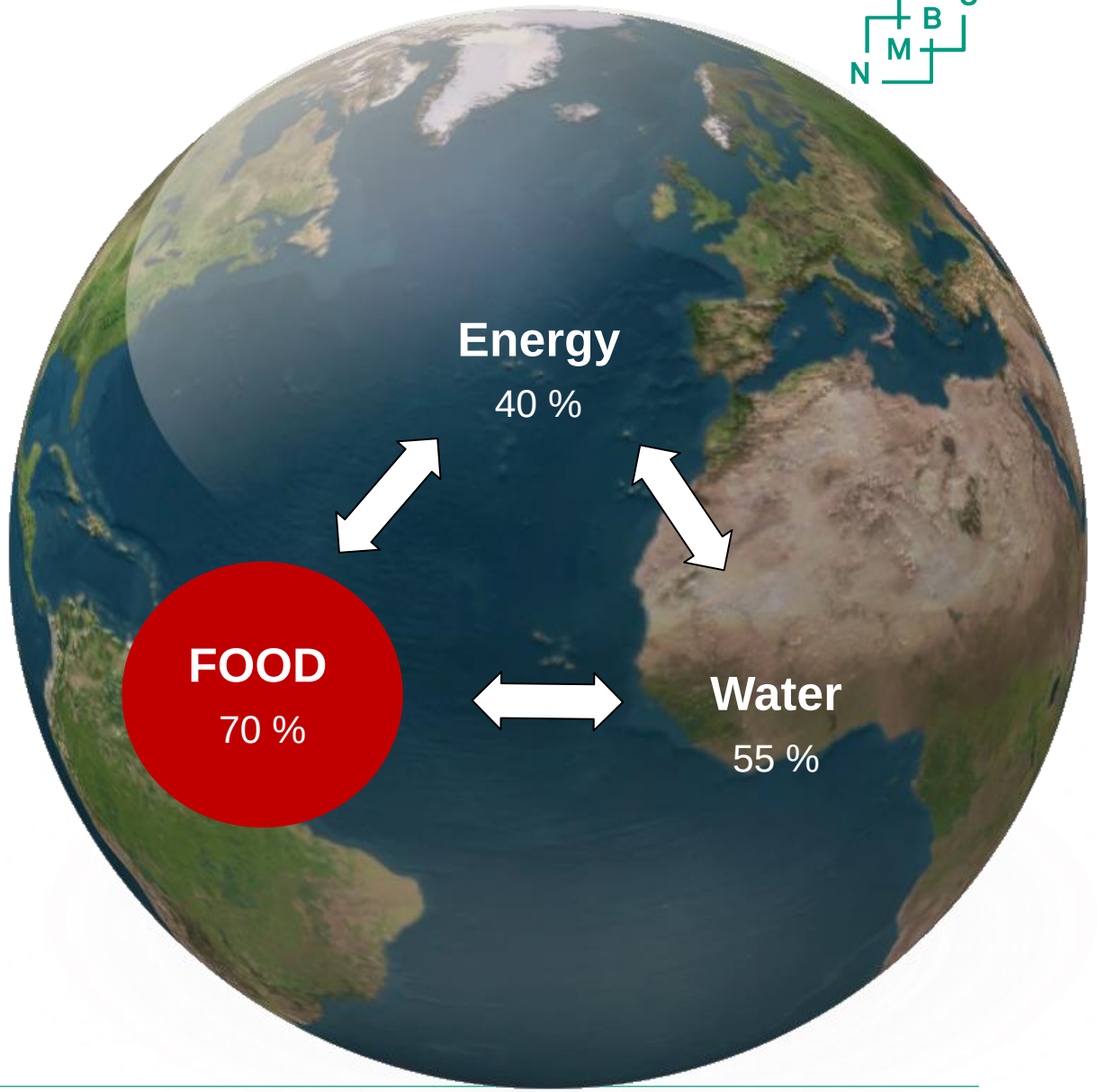
Academic partners and collaborators

Norwegian University of Life Sciences
SLU
Universidad de Chile
University of Minnesota
Driven to Discover
USDA
University of Copenhagen
Aarhus University
The University of Western Australia

Food security and climate

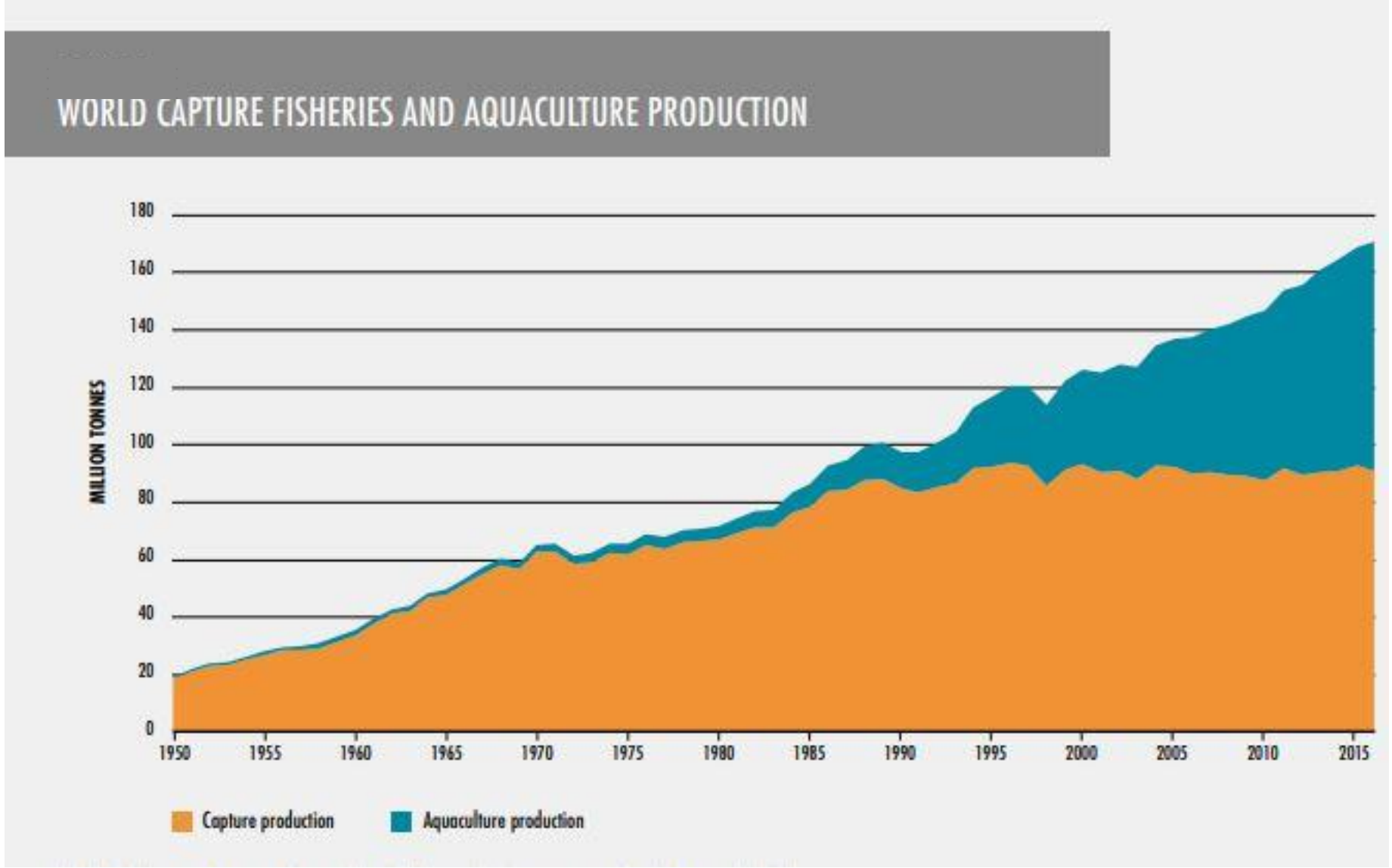
Challenges:

- 2050 ~ 9.7 billion people
- Climatic changes
- Political instability
- Disruption of feed supply chains
- Overreliance on imported feed resources



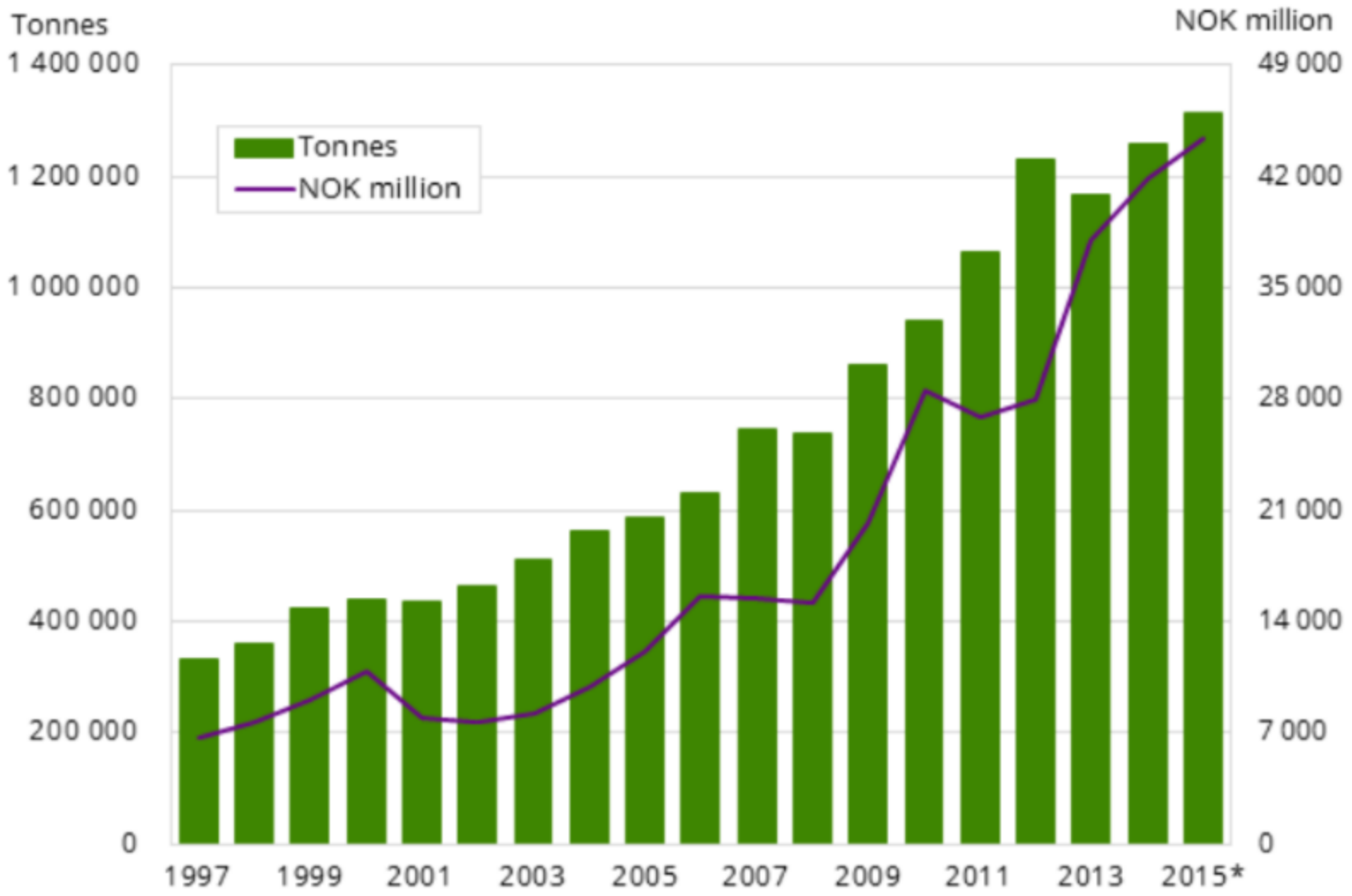
(FAO 2009; OECD 2012)

Aquaculture is expanding to meet world's fish demand



Source: www.WRI/FAO stats Historical data and prognoses1950 - 2050

Salmon production in Norway



Constraints in the growth of the Norwegian Aquacultural industry

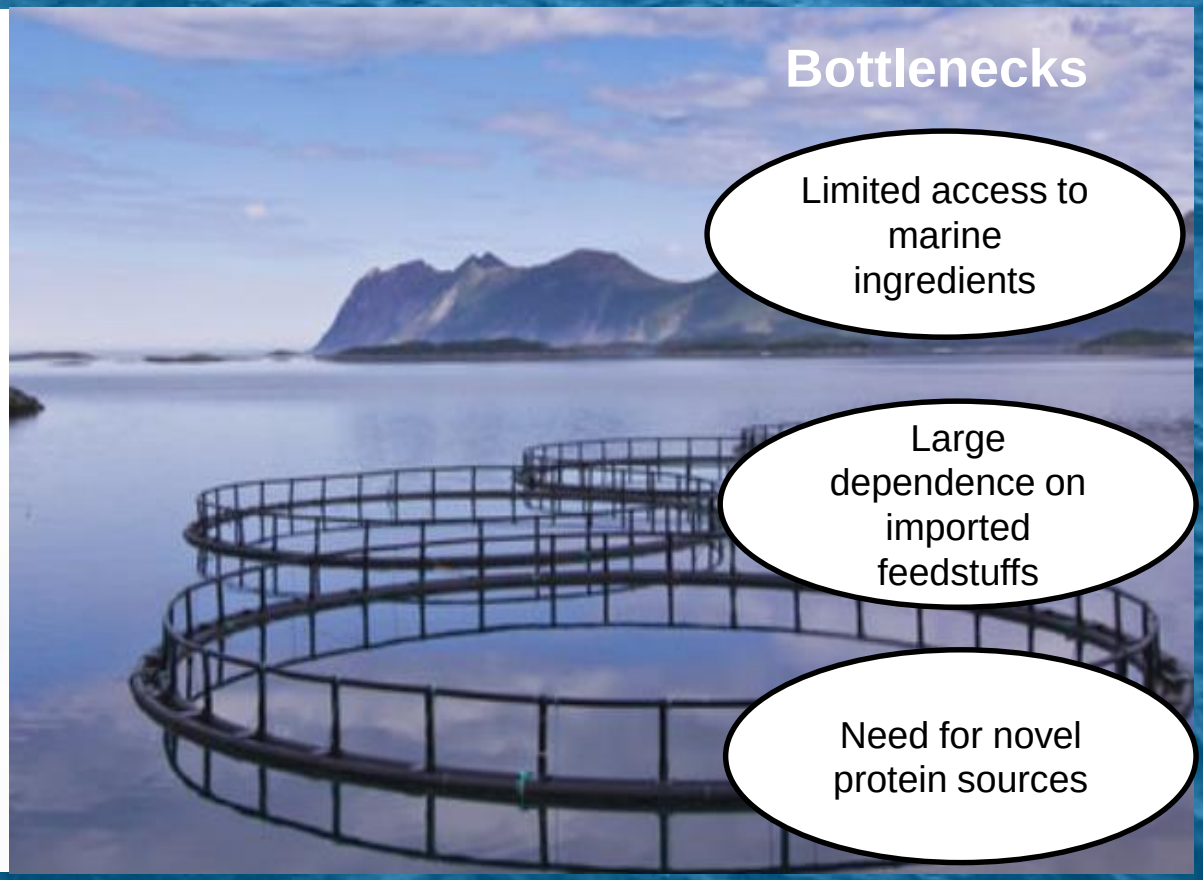
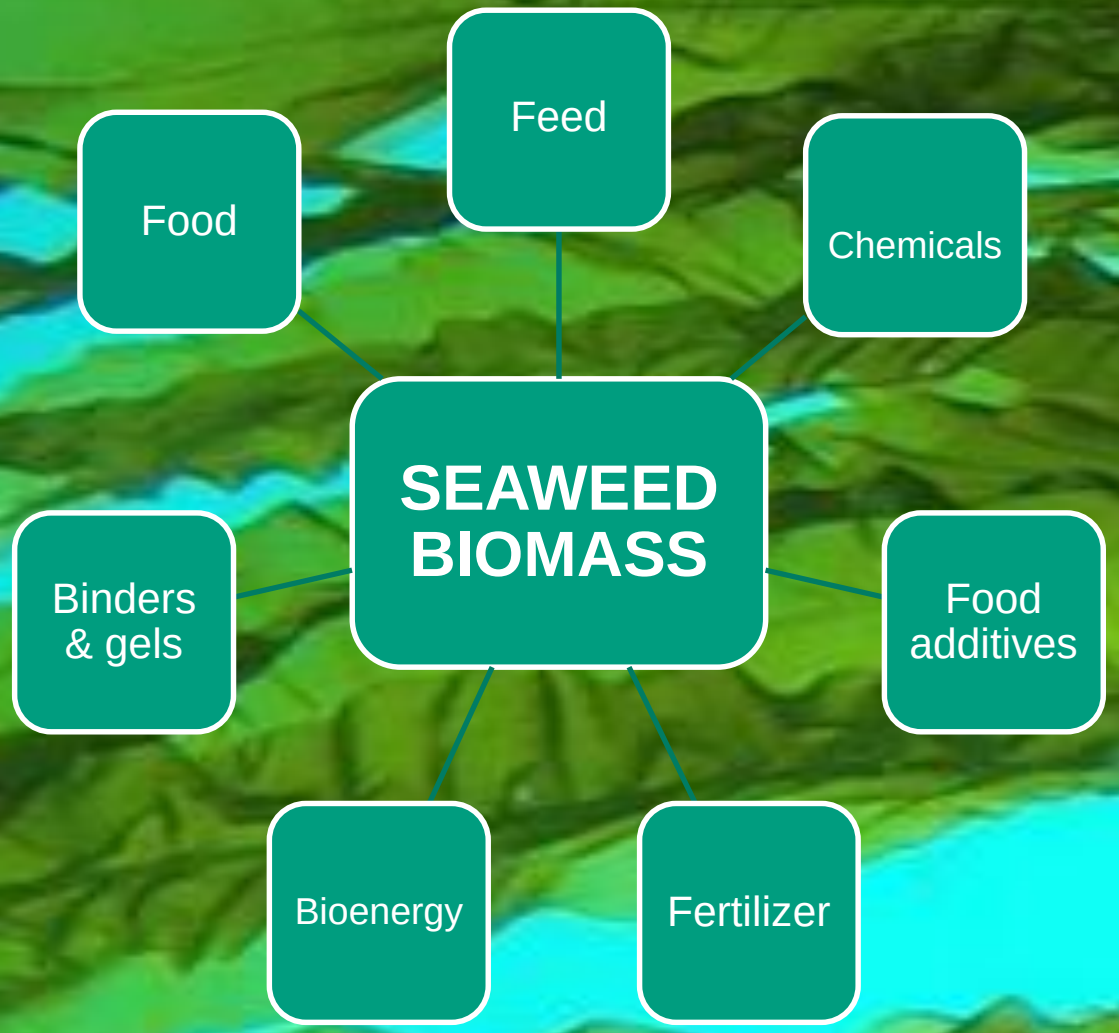


Photo: Alf Ribeiro / Shutterstock.com

Cultivated seaweeds - a potential feed resource

Advantages:

- Large biomass production
- Can be cultivated in sea water
- Don’t require any agricultural land, fertilizers, or fresh water
- Binds and recycles nutrients



Integrated multitrophic aquaculture - IMTA –

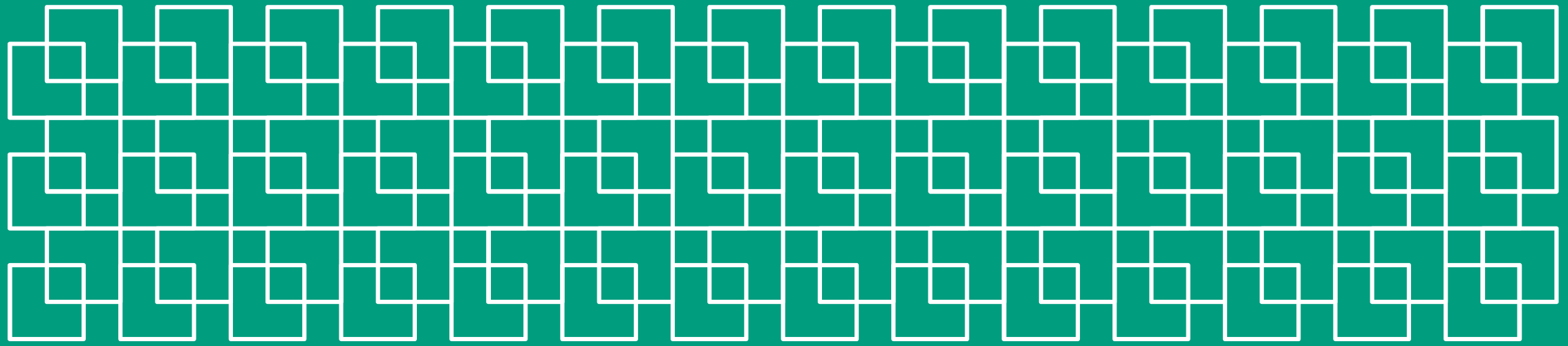
Future aquaculture can produce food, feed and biofuel with a low carbon footprint

OCEAN FOREST

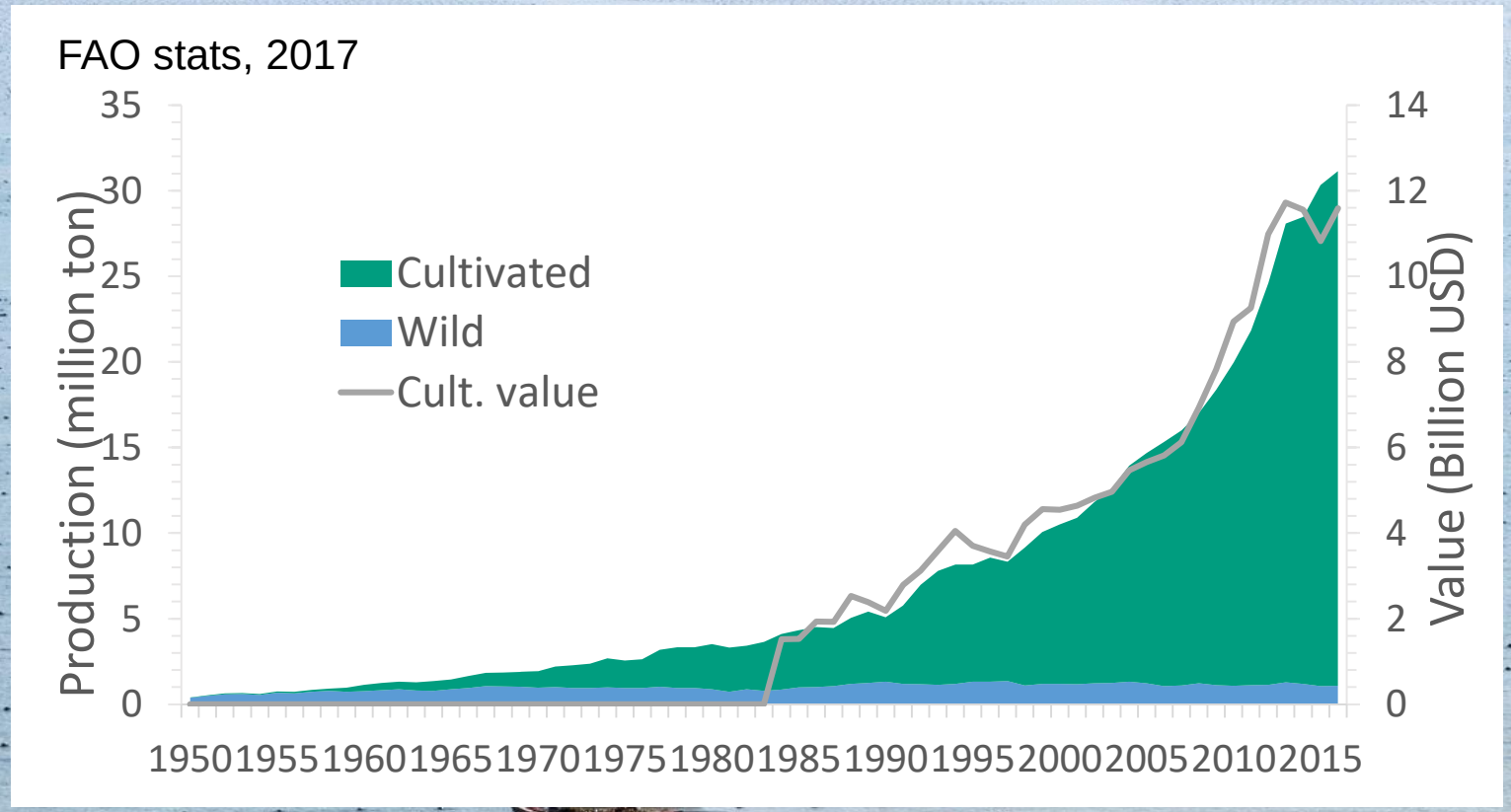
Waste from one species becomes nutrients for others

LERØY BELLONA

Seaweed industry in Norway in a global context & historical perspectives



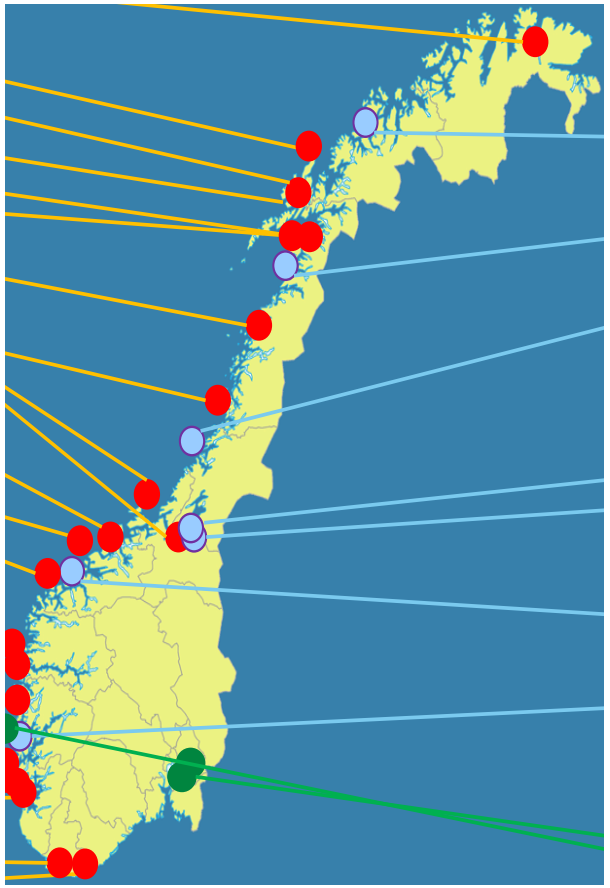
Global seaweed production, 1950-2015



Norway has a unique opportunity to develop a seaweed industry

A new business is on its way – new Norwegian companies sprouting

- Locations for seaweed cultivation

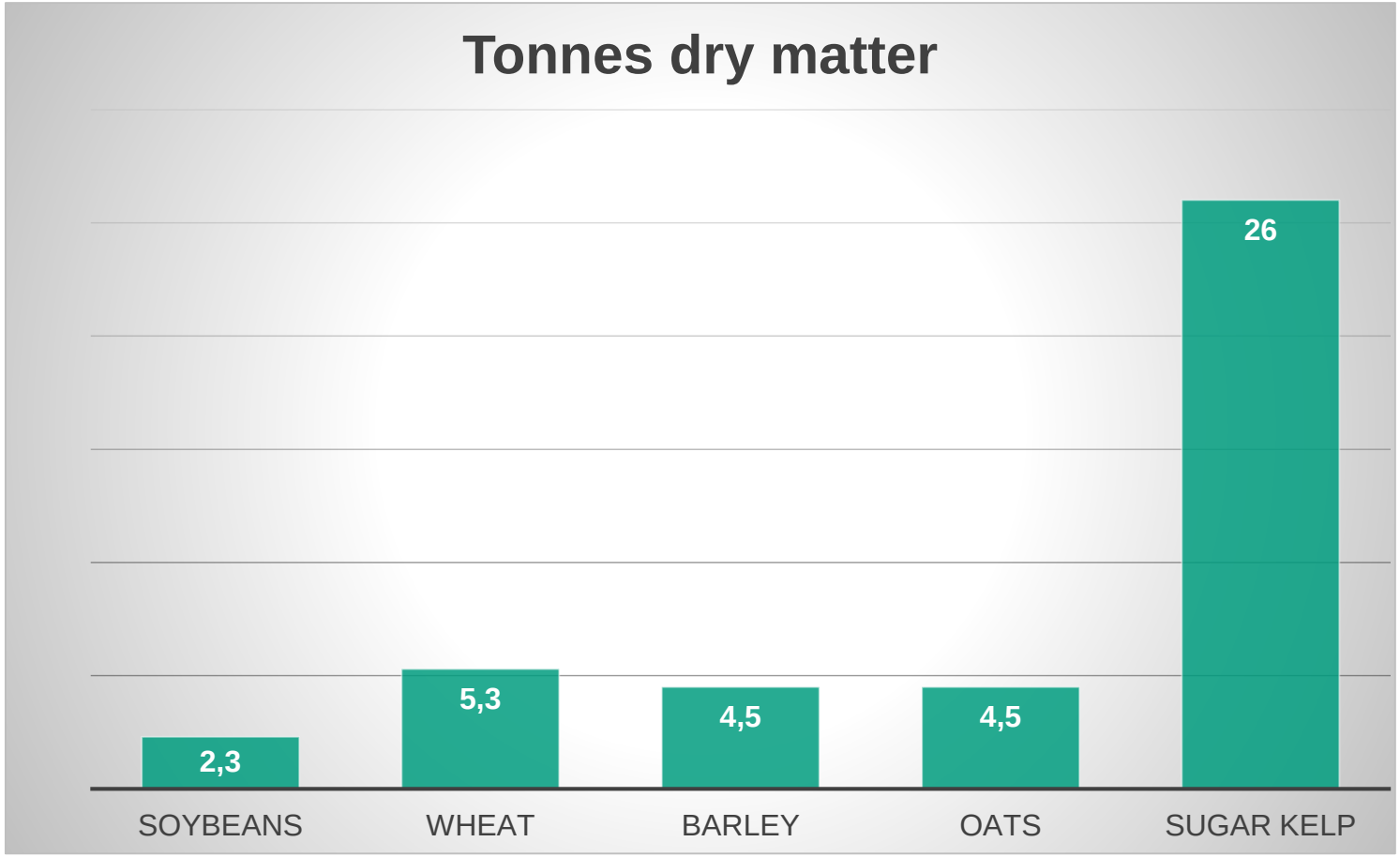


	2014	2015	2016	2017	2018
Consessions	54	164	242	309	406
Locations	12	30	41	55	83
Producton (tonnes)	0	51	60	149	TBA
Value (1000 NOK)	0	178	917	700	TBA

Commercially interesting brown seaweed species:

Saccharina Latissima - sugar kelp,
Alaria esculenta - winged kelp,
Laminaria digitata - oarweed

Sugar kelp *(Saccharina Latissima)*
Production ~ per hectare:



1 hectare seaweed cultivation can provide:

- 170 tonnes wet biomass
- 26 tonnes dry matter
- 15 tonnes carbohydrates
- 3,8 tonnes proteins

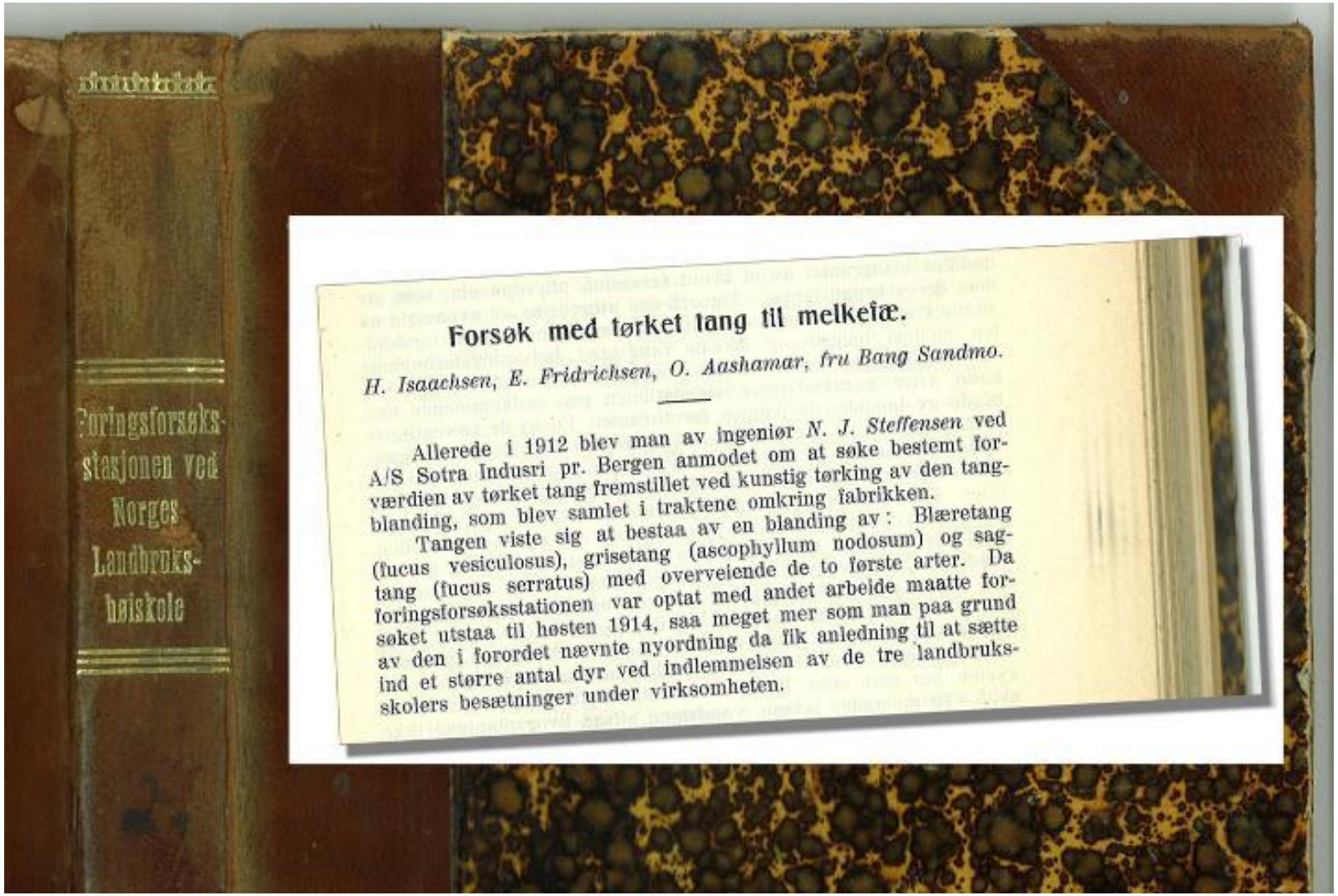
Source: *SINTEF; SSB korn statistikk 2012-2016; FAO stat;

Historical perspective - Seaweed as a feed resource

Europe/Norway	Feed resource during feed scarcity
Chemical analyses	More scientific approach on nutritional value
Premix	Dried kelp meal as a mineral & vitamin source
Health promoting effects	Kelp meal as a functional feed for animal health
Bioactive compounds	Documented positive health effects in animals
Feed application	Added-value products through biorefinery processing

Photos: Shutterstock

Experiment with kelp for dairy cows at NMBU, 1912



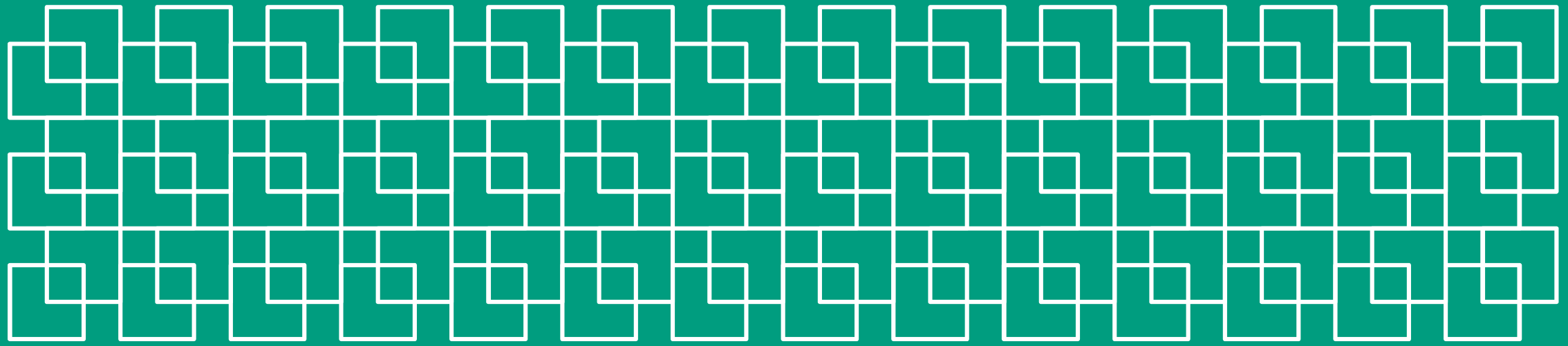
Forsøk med tørket tang til melkefæ.

H. Isaachsen, E. Fridrichsen, O. Aashamar, fru Bang Sandmo.

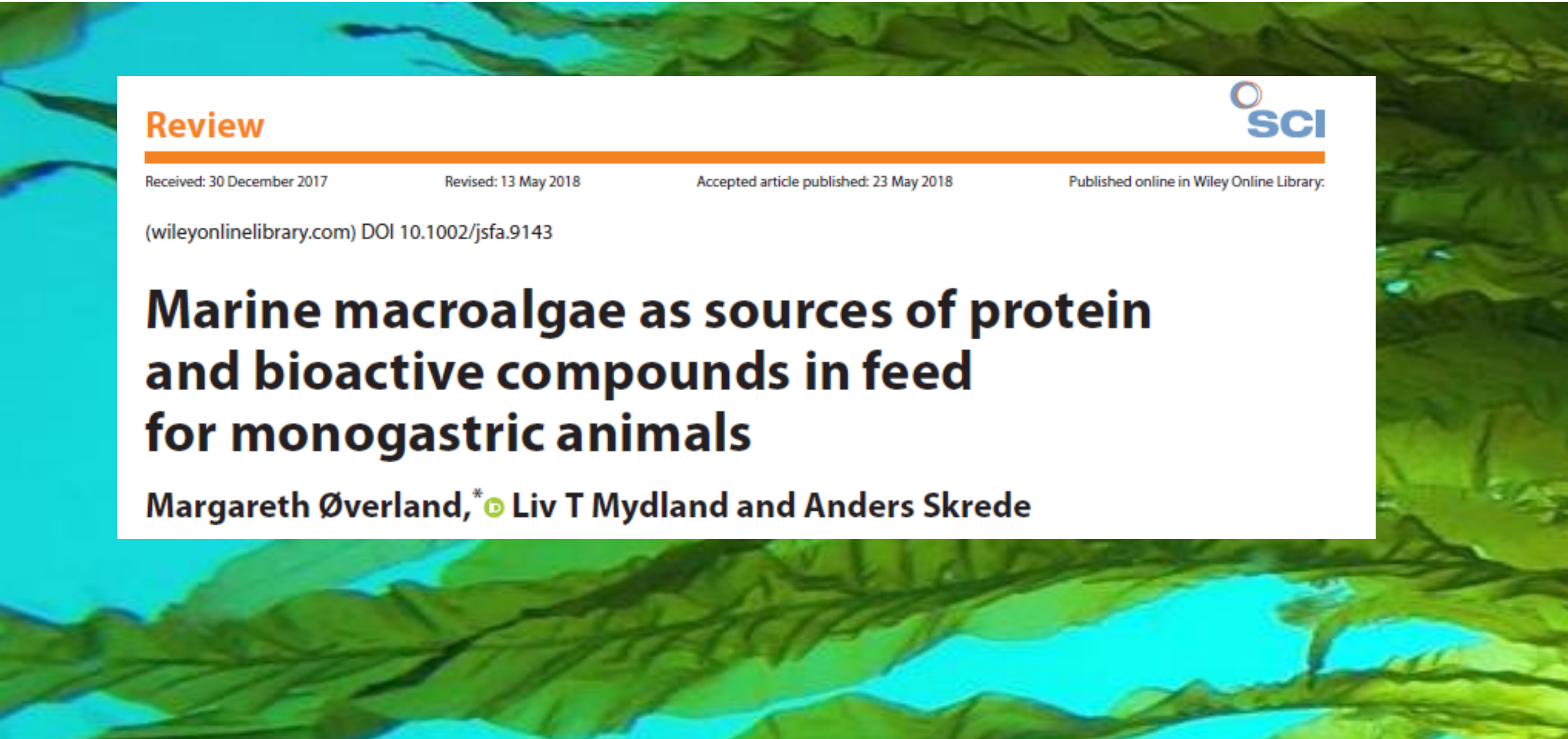
Allerede i 1912 blev man av ingeniør *N. J. Steffensen* ved A/S Sotra Indusri pr. Bergen anmodet om at søke bestemt forværdien av tørket tang fremstillet ved kunstig tørking av den tangblanding, som blev samlet i traktene omkring fabrikken.

Tangen viste sig at bestaa av en blanding av: Blæretang (fucus vesiculosus), grisetang (ascophyllum nodosum) og sagtang (fucus serratus) med overveiende de to første arter. Da foringsforsøksstationen var optat med andet arbeide maatte forsøket utstaa til høsten 1914, saa meget mer som man paa grund av den i forordet nævnte nyordning da fik anledning til at sætte ind et større antal dyr ved indlemmelsen av de tre landbruksskolers besætninger under virksomheten.

Application of seaweed in animal feed



A glance at the seaweed literature



Review

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(wileyonlinelibrary.com) DOI 10.1002/jsfa.9143

Marine macroalgae as sources of protein and bioactive compounds in feed for monogastric animals

Margareth Øverland,* Liv T Mydland and Anders Skrede

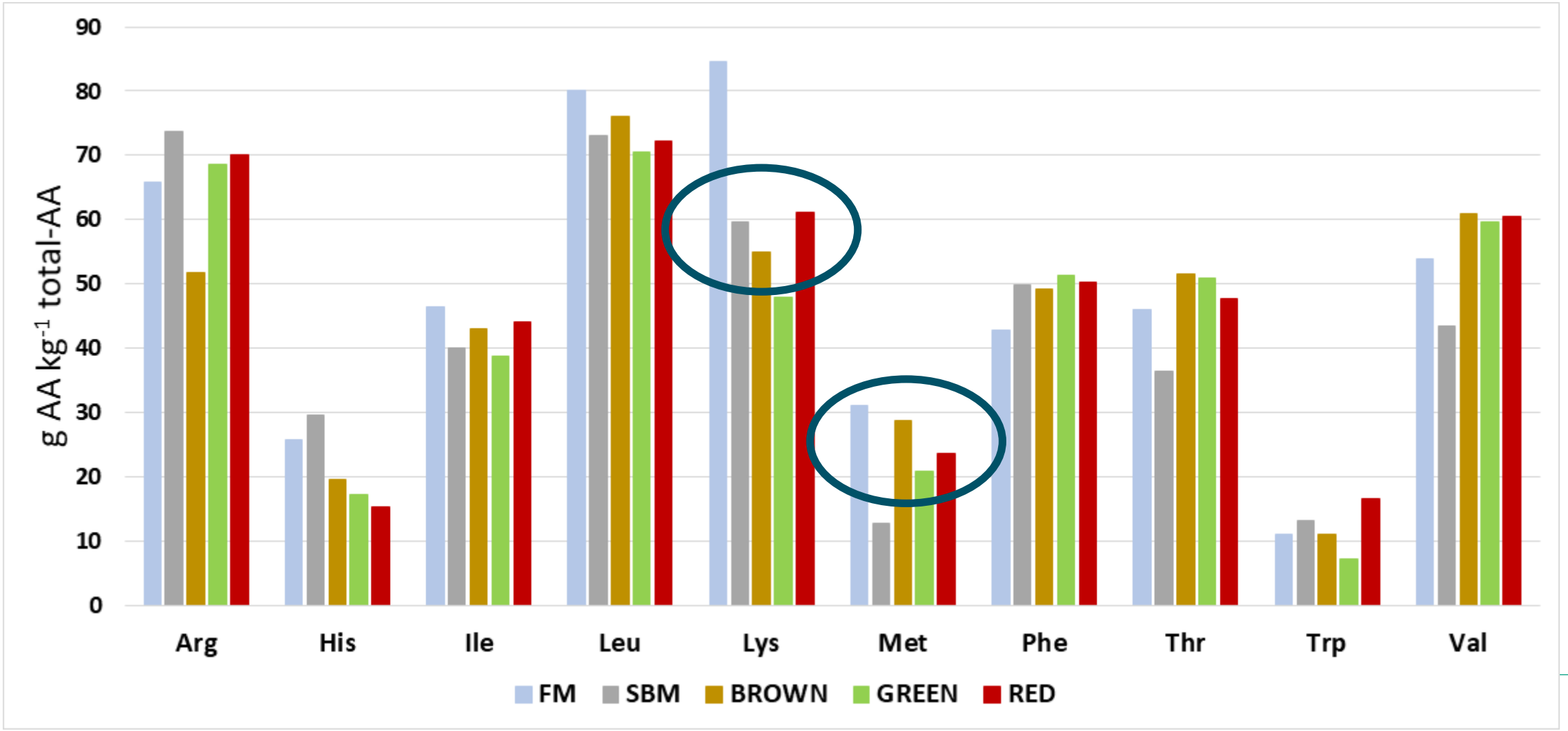
Ranges of chemical composition of seaweeds, g/kg DM

Group	Brown algae *Phaeophyta*	Red algae *Rhodophyta*	Green algae *Chlorophyta*
Water, g/kg wet biomass	610-940	720-910	780-920
Crude protein*	24-168	64-376	32-352
Crude lipids	3-96	2-129	3-28
Polysaccharides	380-610	360-660	150-650
Ash	150-450	120-422	110-550

*Crude protein is based on a n to protein factor of 5

Source: Øverland et al., 2019; Values are for typical seaweed species reported in the litterature

Essential amino acid profile in brown, green and red seaweeds compared to fishmeal and soybean meal, g EAA kg^{-1} of total AA



Feeding trials with whole green seaweeds (*Ulva spp*.) in diets for monogastric animals

Species	Level	Effect	Reference
Green algae			
U. lactuca	0-3%	Broiler chicks: Did not affect ADG, ADFI or FCR, but improved dressing%, breast meat %, &	Abudabos et al., 2013
U. Enteromorpha prolifera powder			Wang et al. 2013
U. rigida			Ventura et al., 1994
U. Rigida			Valente et al., 2006
50/50% mixture of *U. rigida* and *U. lactuca*			Marinho et al. 2013
U. Latuca meal	5, 10, 15%	Gilthead seabream: Improved growth, FCR, protein efficiency ratio, and survival. Best results at 5% inclusion level. All diets stimulate feed intake, and improved weight gain.	Wassef et al., 2005
U. Pertusa meal	12%	Red sea bream: Increased weight gain, FCR and muscle protein deposition.	Mustafa et al., 1995

- Green seaweeds show potential as a feed resource
- Inconsistent results on animal performance
- Positive effect on growth performance & carcass quality of broiler chickens
- Positive effects on growth performance of fish
- Improved performance and digestibility by targeted processing

Feeding trials with whole red seaweeds in diets for monogastric animals

Species	Level	Effect	Reference
Red algae			
P. Palmata meal	5, 10, 15%	Atlantic salmon: No difference in growth and FCR, thus it was concluded that *P. palmata* can be a suitable component in feed.	Wan et al., 2016
P. Palmata meal	5%	Atlantic salmon: Enhanced yellow/orange color of fish fillets due to deposition of algae pigments. It was concluded that	Moroney et al.2015
P. purpurea meal			avies et al.1997
Porphyra spp. (> 90 *umbilicalis*			alker et al., 2009
P. dioca			ler-Vila et al. 2009
Gracilaria vermicul			raujo et al. 2016
Gracilaria bursa-pa and *Gracilaria corn*			lente et al. 2006
Gracilaria pygmaea			toudeh and ardani 2017
Gracilaria spp. or a mix of 2.5% *Gracilaria*, 2.5% *Ulva* & 2.5% *Fucus* spp.	7.5%	European seabass: No adverse effect on growth performance at 7.5% inclusion level.	Peixoto et al. 2016
P. yezoensis meal	5%	Red seabream: Improved weight gain , FCR and muscle protein retention.	Mustafa et al., 1995
P. yezoensis Ueda meal	15, 30%	Nile tilapia: Improved growth, FCR, and protein efficiency ratio at 15% inclusion and no adverse effect on growth performance at 30% inclusion.	Stadtlander et al., 2013

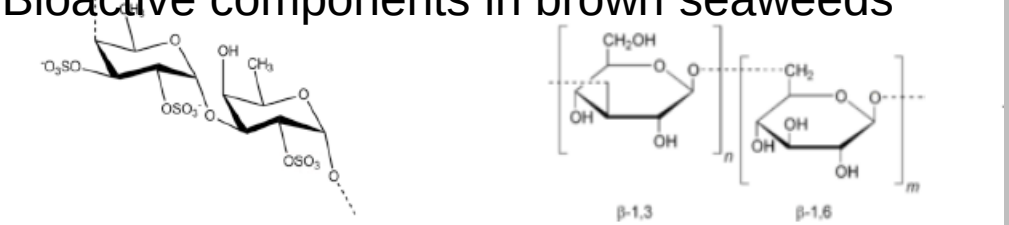
Most work on *Palmaria palmata*, *Phorphyra & Gracilaria* spp
Red seaweeds show potential as a functional feed resource for fish:

- Improve health and welfare
- Improve taste of feed
- Increase pigmentation
- Improve product quality of fish muscle

Brown seaweed as feed resource for monogastric animals

- Alternative protein source with targeted processing
- Large potential in functional feeds Ex. *Ascophyllum nodosum, Laminaria spp*

Bioactive components in brown seaweeds



Fucoidan (sulphated polysaccharide)

Laminaran (β-1,3/1,6-glucan)

Documented functions:

- **Fucoidan:**
  - Immunomodulating
  - Antithrombotic
  - Anticoagulant
  - Antiviral (anti-infectious)
  - Antibacterial / probiotic
  - Antitumor
  - Antioxidant
  - Anti-inflammatory

- **Laminarin:**
  - Immunomodulating
  - Antithrombotic
  - Anticoagulant
  - Antiviral (anti-infectious)
  - Antibacterial / probiotic
  - Antitumor
  - Antioxidan
  - Antiinflammatory

Source: Holdt and Kraan 2011; Brown et al., 2014

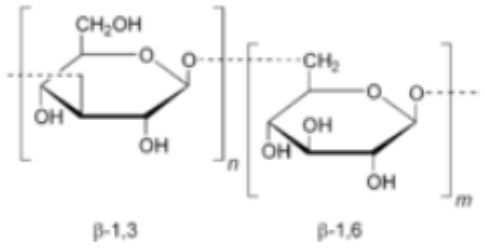
Photo: M. Øverland

Feeding brown seaweed extracts to weanling pigs

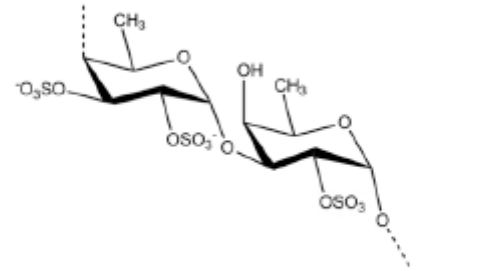
- Extract from *Laminaria* Spp or *Ascophyllum nodosum*
- Positive effect on growth performance
  - Improved nutrient digestion & uptake from gut
  - Improved villus architecture
  - Increased numbers of nutrient transporters
- Improved intestinal health
  - Increases population of beneficial bacteria
  - Increase VFA concentration and reduces pH
  - Modulates immune system
  - Improves gut barrier function

Source: Øverland et al., 2019

Inconsistent results with laminarin and fucoidan



Laminaran (β-1,3/1,6-glucan)



Fucoidan (sulphated polysaccharide)

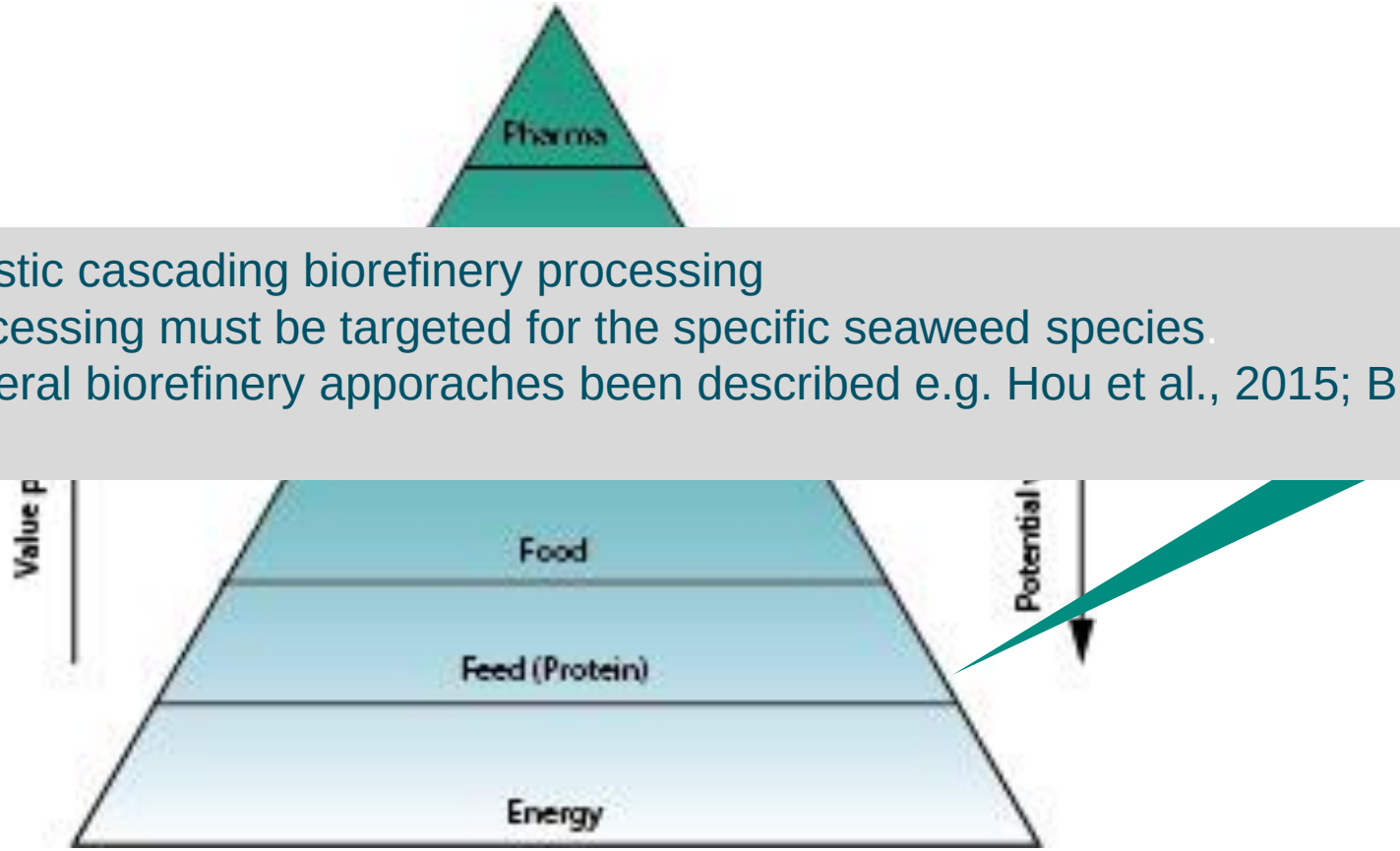
Presence of inhibitors in SW extracts
Differences in purity of the extracts due to extraction methods applied
Differences in bioactivity of laminarin and fucoidan among SW sources,
Differences in experimental designs

Different mode of action due to different biochemical structures

Source: Øverland et al., 2019

Processing of seaweed for optimized value creation

Value creation and volume potential of different seaweed applications

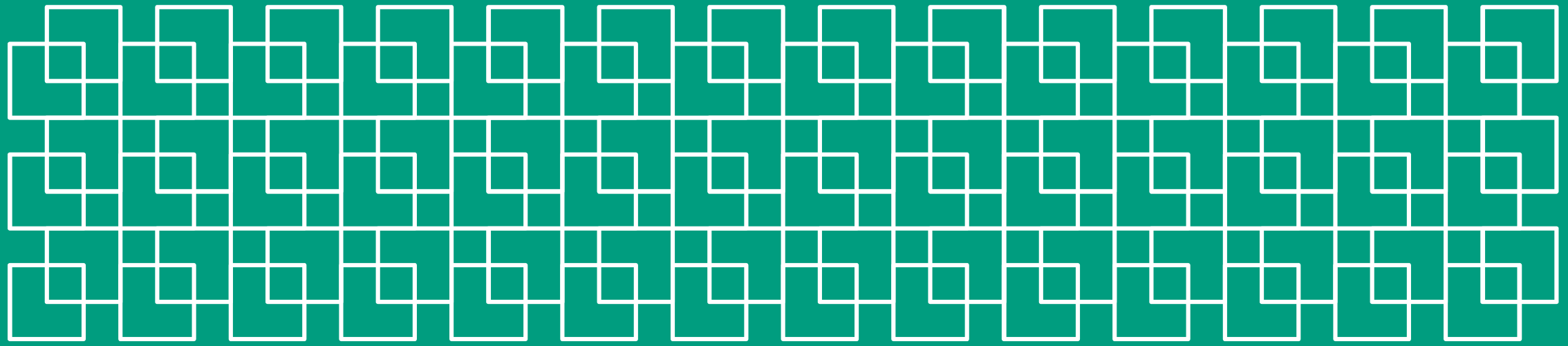


Use of seaweed in feeds provides opportunity for a profitable bulk application

- Holistic cascading biorefinery processing
- Processing must be targeted for the specific seaweed species.
- Several biorefinery apporaches been described e.g. Hou et al., 2015; Bikker et al., 2016; Baghel et al., 2016.

Source: Øverland, Mydland & Skrede, 2014;

Our results on Seaweeds



The Seaweed Energy Solution’s pilot farm in Frøya in Norway

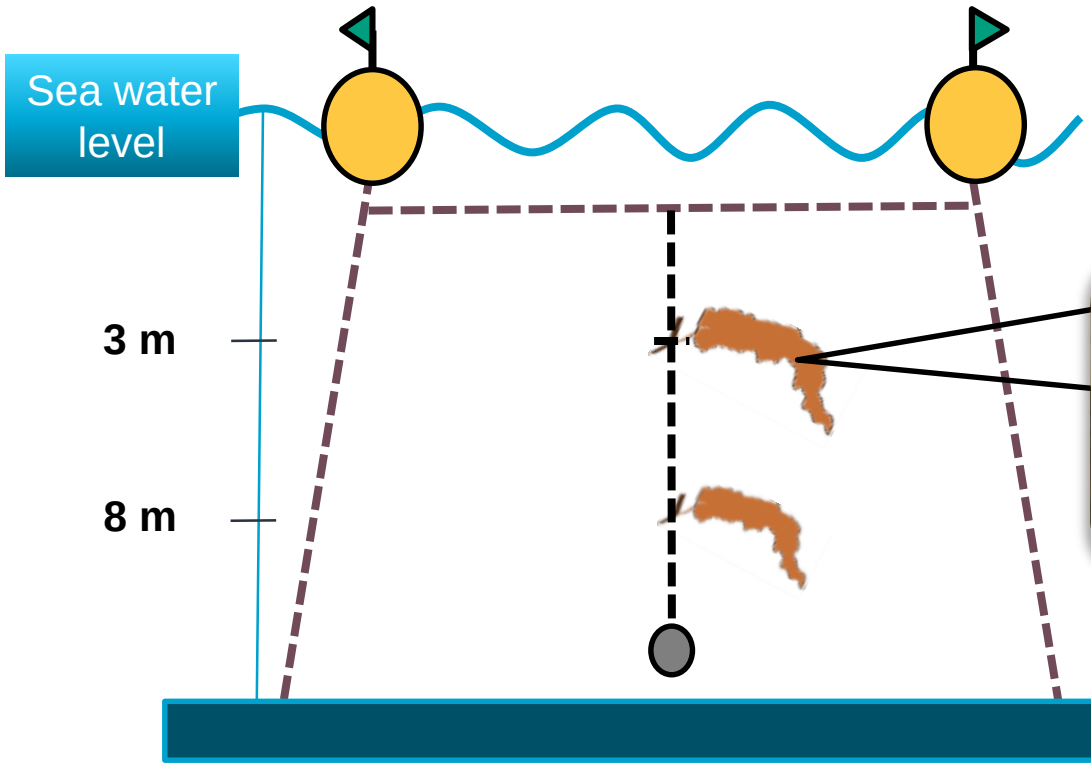
SEAWEED ENERGY SOLUTIONS AS

Sugar kelp – harvest in the spring

Photo: SES, Frøya, Norway

Biomass production at different sea depth and harvest points

Seaweed cultivation at Frøya



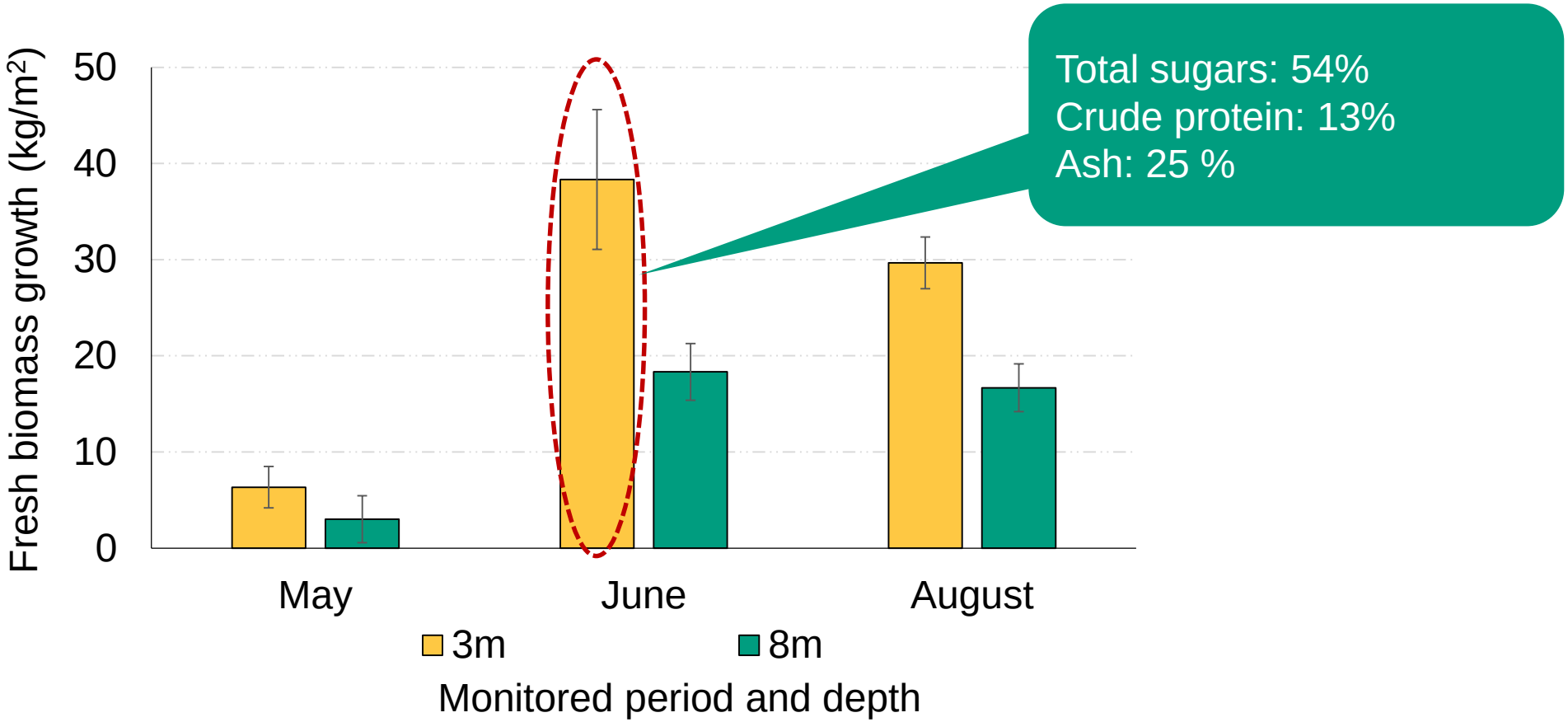
Saccharina latissima

Harvested
- **May**
- **June**
- **August**

Biomass growth and **chemical characterization**
- Glucose, mannitol, fucose
- Uronic acids
- Protein
- Amino acids
- Minerals

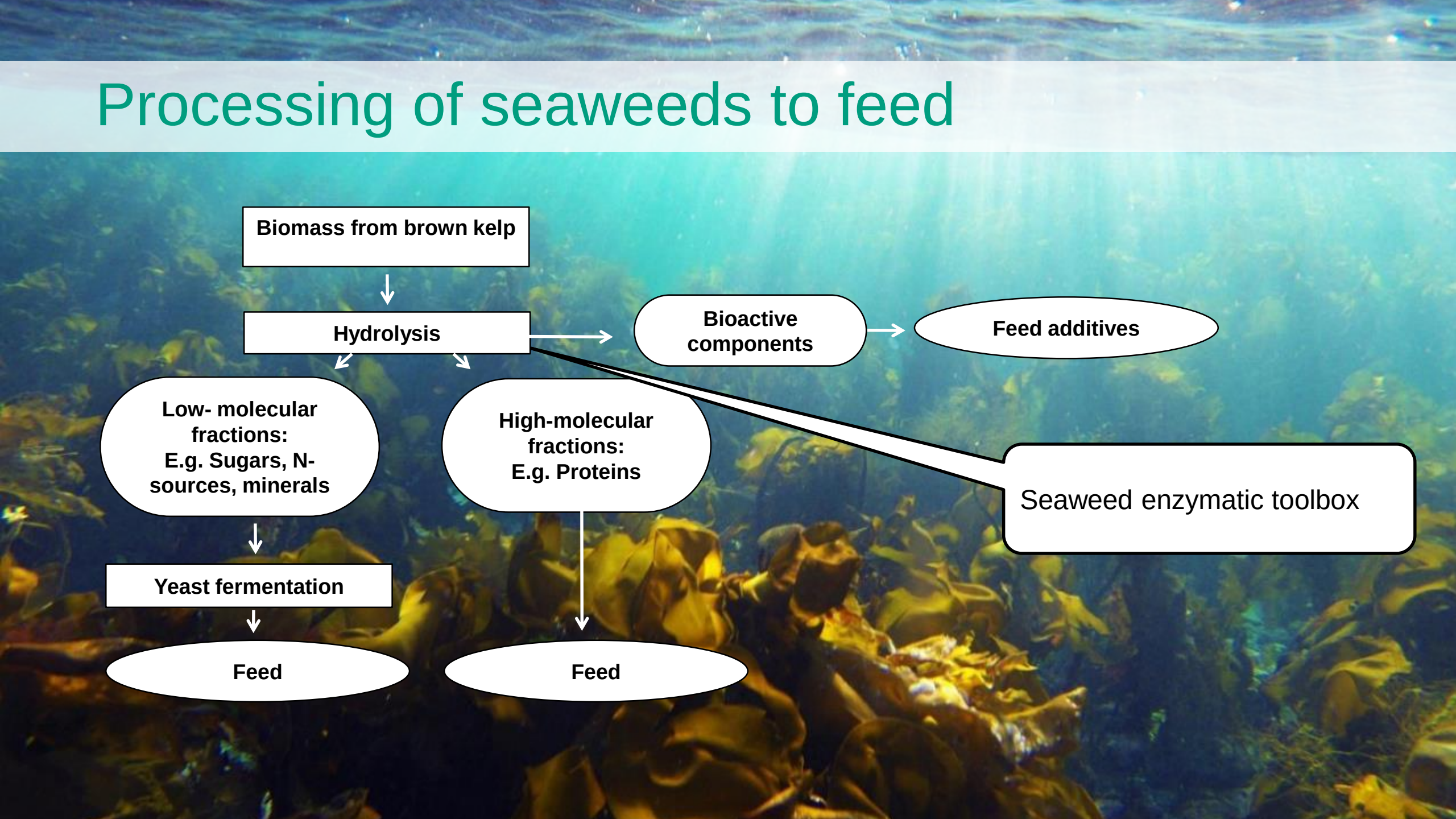
S. latissima deployed in February at 3 m and 8 m depth

Biomass production of cultivated *S. latissima*



Source: Sharma et al., 2018, Algae Research 32, 107-112

Processing of seaweeds to feed



Enzymatic saccharification of brown seaweed (*S. latissima)* to produce fermentable sugars

Max sugar yield from seaweed was obtained:

- drying at 30ºC
- using a combination of in-house alginate lyases & cellulases (CellicCTec2)
- at high solid loading in the bioreactor of 25%

Frozen seaweed

Grinded

Drying:

Ultra grinding

Final sample

\+ Solid loading in the bioreactor
CellicCTEC2 and in house Alginate lyases

Source: Schrama & Horn, 2016, Bioresource Technology, 213, 155-161; Ravanal et al., 2017, Algal Research, 26:287.293

Co-fermentation of seaweed biomass and spruce trees
An integrated biorefinery process to produce feed

Biomass

Spruce trees

Brown seaweed, *Saccharina Latissima*

Brown Seaweed	Spruce wood
Composition	
• **Laminarin** • Mannitol • **Alginate** • Fucoidan • **Minerals** • **Amino acids**	• **Cellulose** • Hemicellulose • Lignin • Extractives
Enzymes	
• **Laminarinase** • β-glucosidases • **Alginate lyases**	• **β-glucanase** • **β-glucosidases** • Auxiliary

Yeast

Proof of concept:
Yeast grew well on a media based on tree sugars and seaweed nutrients

Source: Vaaje-Kolstad et al., Science, 2010 ; Shrama, S. et al., 2019, J. of Agric. & Food Chemistry

Isolating bioactive components from seaweeds

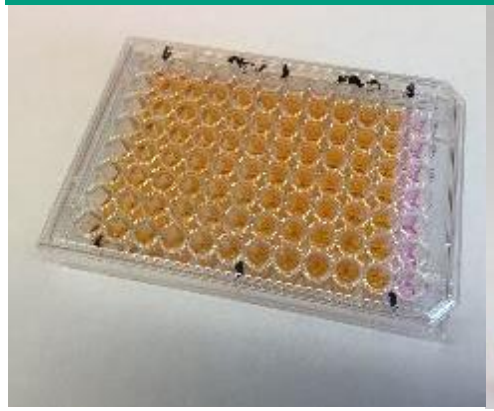
Fucoidan and laminarin

Grinding

HCl hydrolysis

- **Precipetation**
  - Precipitating out alginate, filtration & centrifugation
- **Fractionation**
  - Fractionating by step-wise filtration

In vitro screening with seaweed extracts



- GEA membrane filtration
- Spiral membranes with different sizes

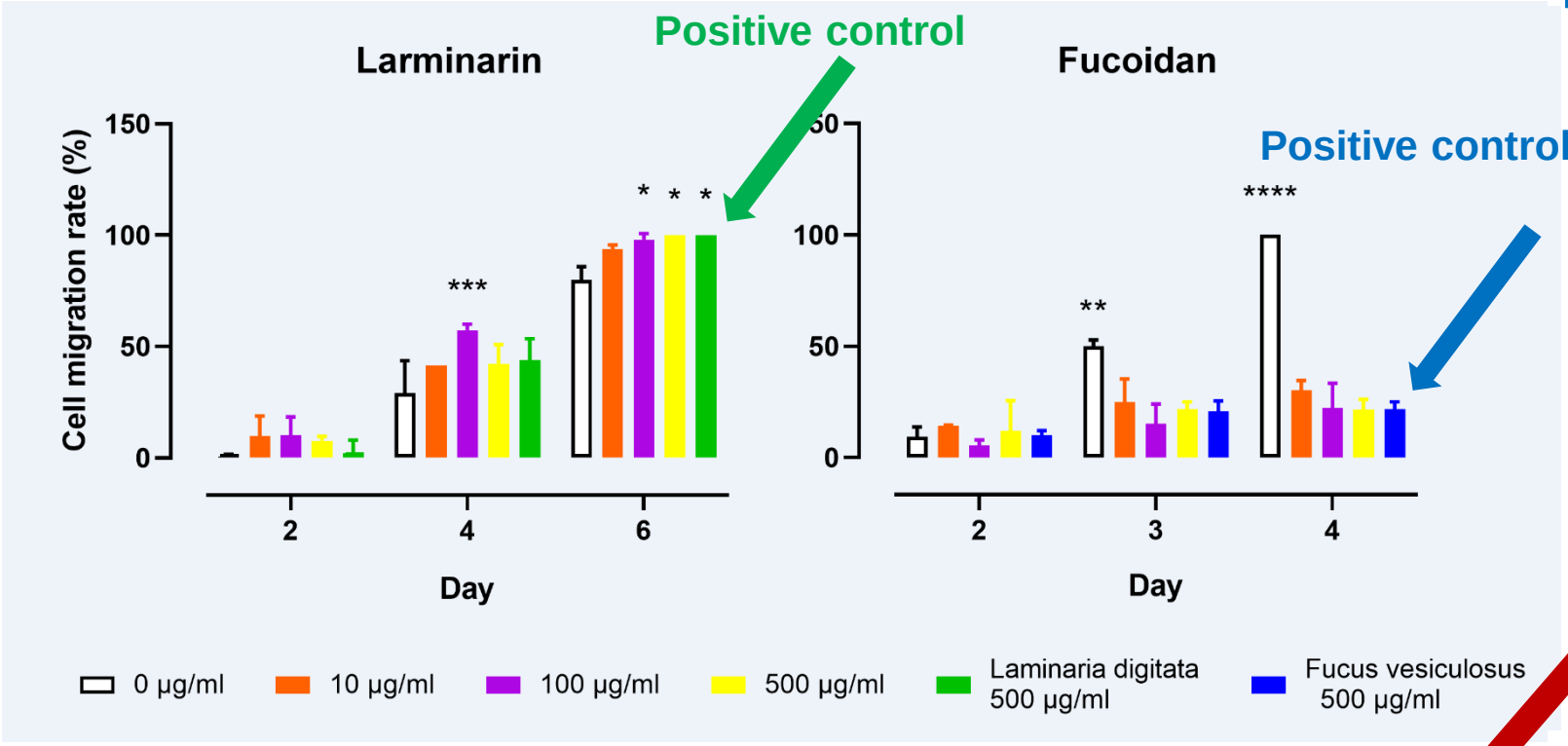
- HPLC based analyses of sugars, manitol and uronic acid

Source: Foods of Norway team

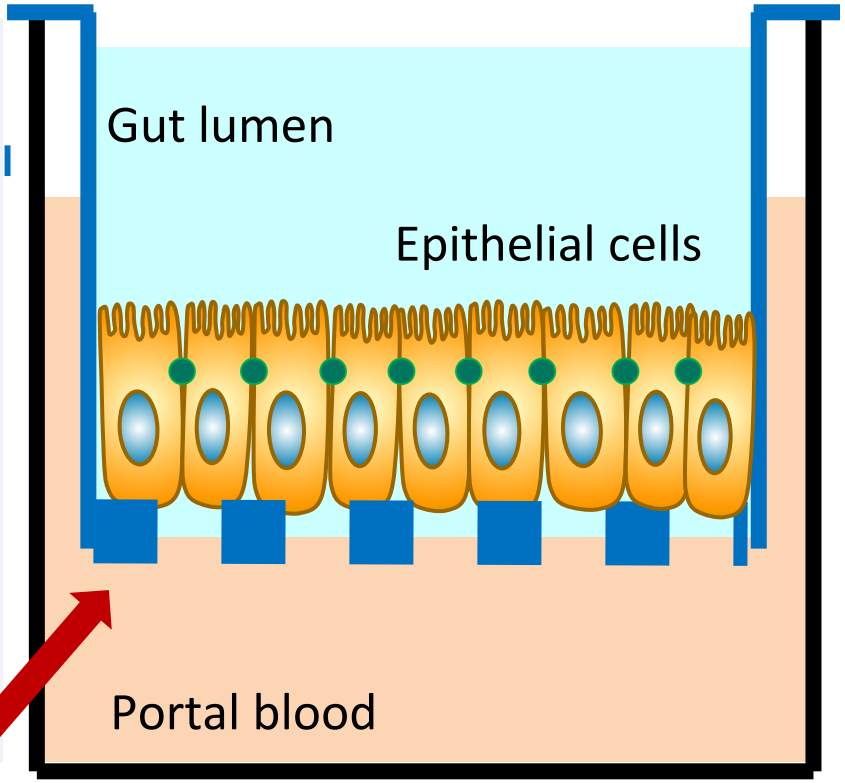
In vitro screening – e.g.wound healing assay

Epithelial cells from rainbow trout

Cell migration rate, % of wound closure rate



Rainbow trout epithelial cells

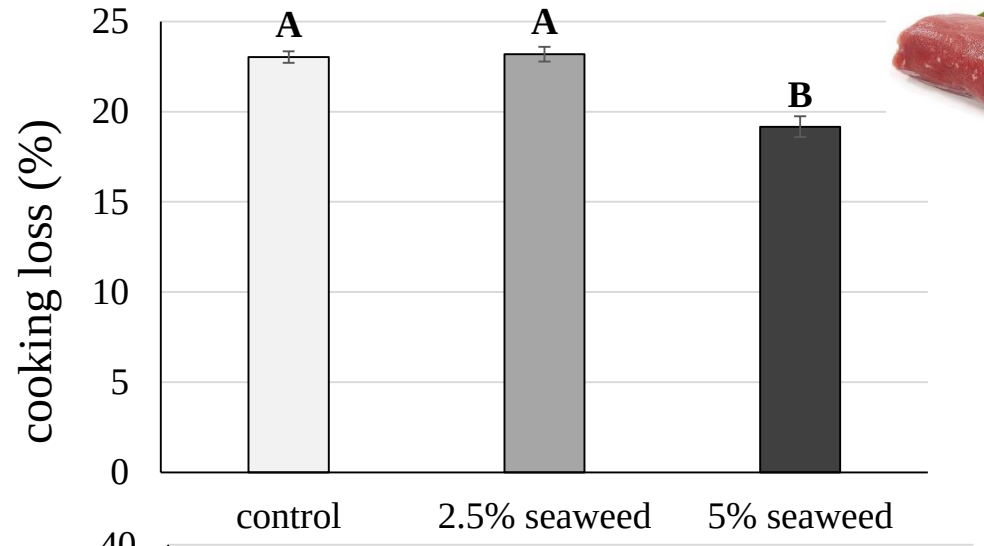


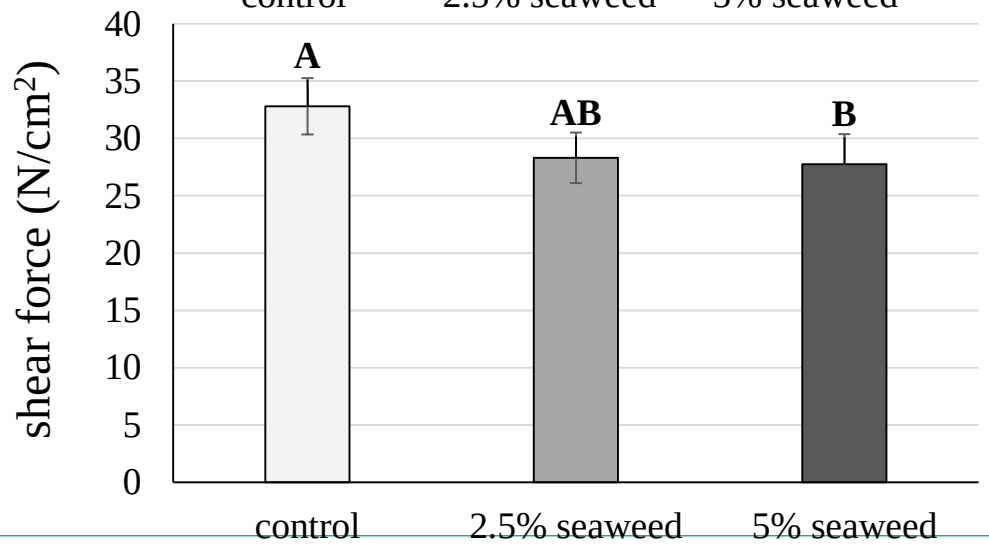
- Permeable membrane

Source: Oma, 2018; MSc Theses, NMBU

Seaweed (Saccharina latissima) in diets for lamb

Effect of seaweed on lamb meat quality – cooking loss & texture (N/cm²)





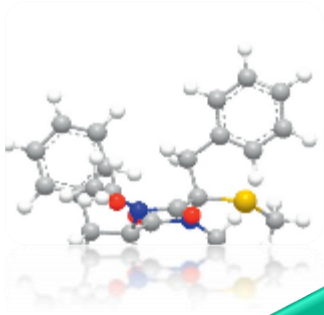
Significance level (P<0.05)

Lamb meat consumer test

Methods to evaluate product quality of the lamb meat

Profiling molecular compounds in meat that can affect product quality

GC/MS-based method for (volatile) metabolite analysis	HPLC-QTOF method for metabolite analysis

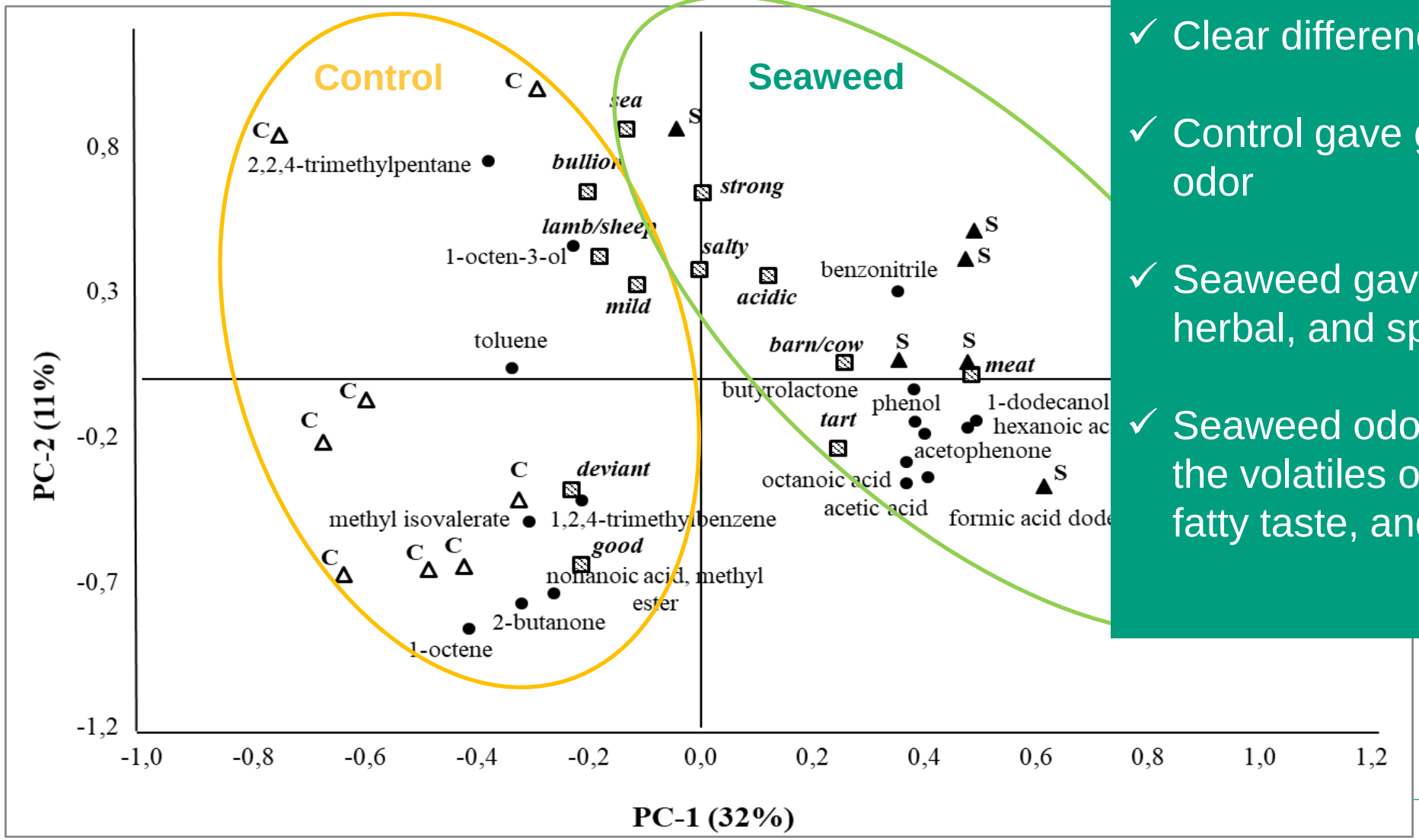


Metabolome

To understand how seaweed can affect the sensory traits of red meat

Impact of gut microbiome on meat quality – metaproteomic analyses of rumen fluid

Consumer odor attributes of meat combined with volatiles of lamb fat tissue



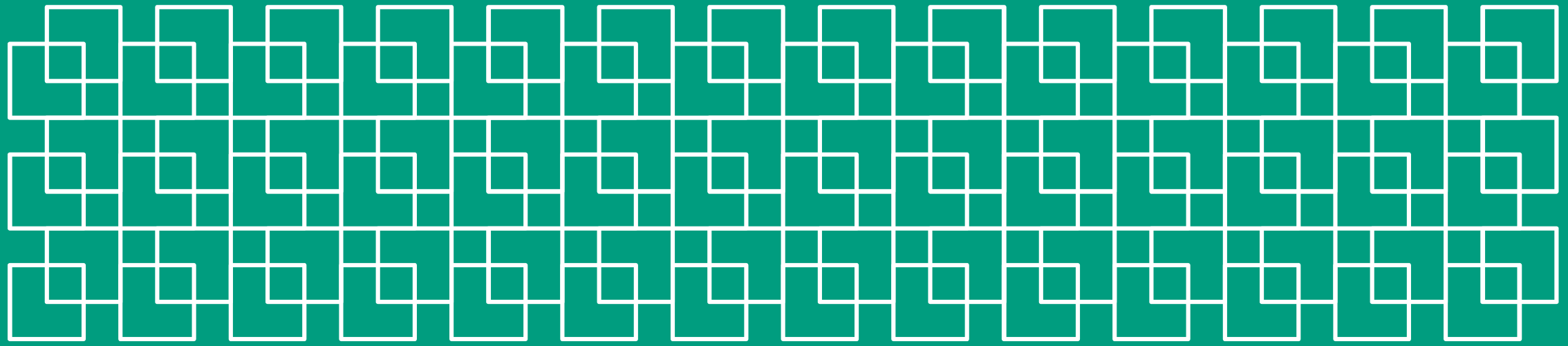
- ✓ Clear difference between the diets
- ✓ Control gave good, mild and bullion odor
- ✓ Seaweed gave a salty, strong, herbal, and spicy odor
- ✓ Seaweed odor was correlated with the volatiles organic acids, sweet, fatty taste, and almond taste

Source: Foods of Norway prelim data;

Seaweed in diets for lamb – effect on meat quality

- Gave a unique quality of lamb meat that could be used to provide niche products to the market
- Increased the iodine level in the lamb meat

Challenges with use of seaweed in animal feed



Cultivating sugar kelp

- Challenges
  - Area use, uneven growth, diseases, harmful components, harvest, storage, processing & logistics

Levels of iodine, arsenic & cadmium
Levels mercury and lead
Levels of persistent organic pollutants

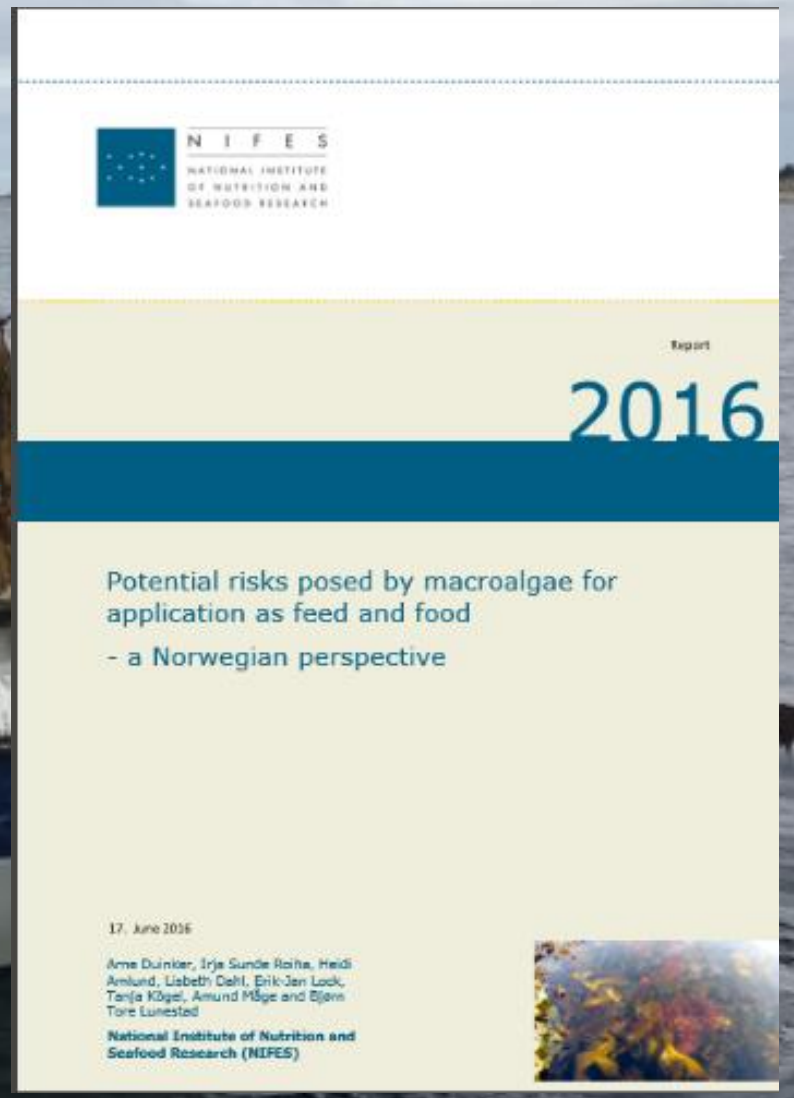


Photo: Øverland, Frøya 2017; Norway

Environmental aspects of seaweed farming

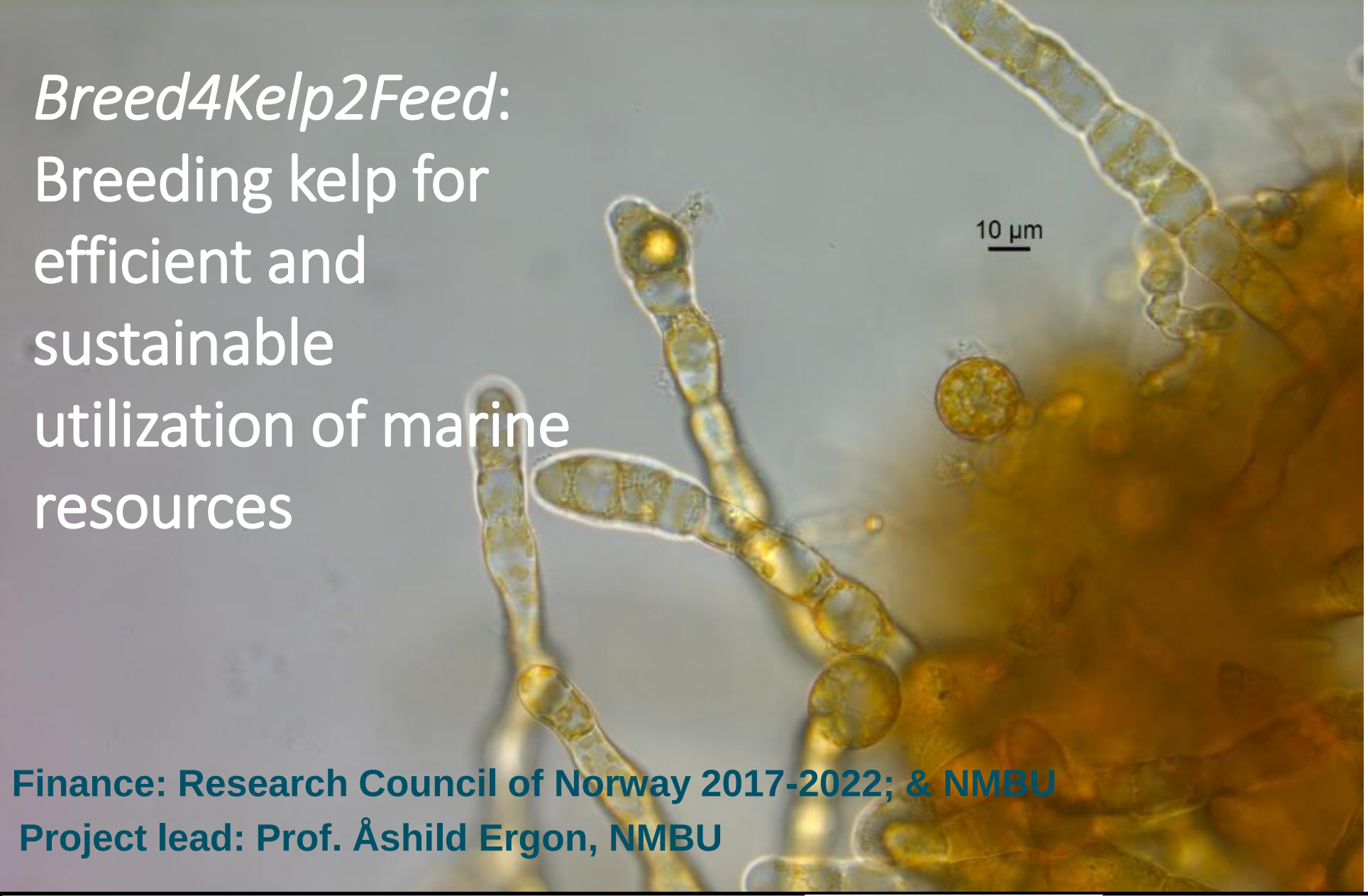
frontiers

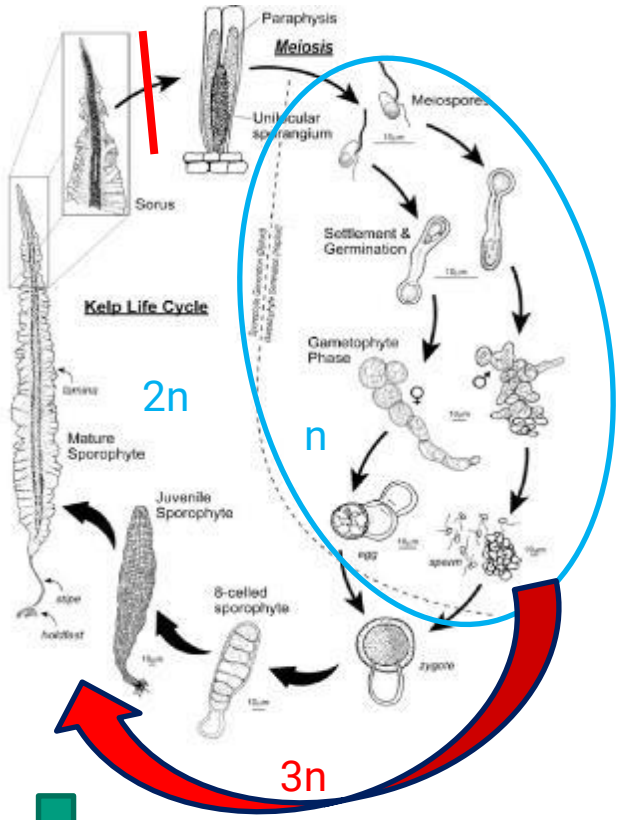
The environmental risks associated with the development of seaweed farming in Europe - prioritizing key knowledge gaps

Iona Campbell[1], Adrian Macleod[1*], Christian Sahlmann[2], Luiza Neves[3], Jon Funderud[3], Margareth Overland[2], Adam Hughes[1], Michele Stanley[1]

[1]Scottish Association For Marine Science, United Kingdom, [2]Norwegian University of Life Sciences, Norway, [3]Seaweed Energy Solutions (Norway), Norway

Breed4Kelp2Feed: Breeding kelp for efficient and sustainable utilization of marine resources





Breeding in Norway without genetic pollution

Finance: Research Council of Norway 2017-2022; & NMBU

Project lead: Prof. Åshild Ergon, NMBU

NMBU · FOODS OF NORWAY · SINTEF · SEAWEED ENERGY SOLUTIONS AS · AquaGen · SAMS · UNIVERSIDAD DE LOS LAGOS

The BIOFEED project

BIOFEED - **Novel salmon feed by integrated bioprocessing of non-food biomass**

Finance: 2 Mill € & 33% Co-finance from NMBU
Time frame: 2014 – 2019
Project lead: Prof. Margareth Øverland

Norwegian seaweed Biorefinery platform (2019-2022)

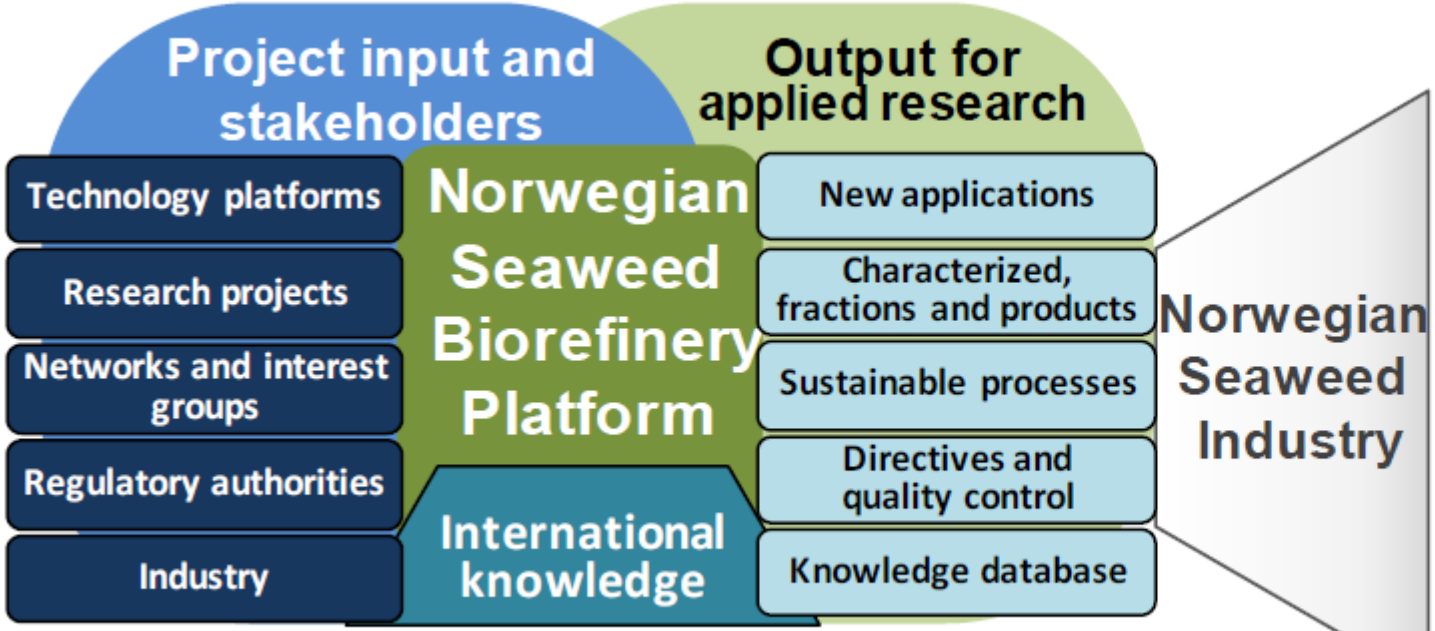


Figure 1: Basic idea of the proposed Norwegian Seaweed Biorefinery Platform

Partners:

- Norwegian Univ. of Science and Technology
- SINTEF
- NMBU
- Nofima
- Møreforskning

Conclusions

- Use of unprocessed seaweed as a feed resource is limited
- Processed seaweed is an interesting alternative protein source
- Seaweed extracts have great promise in functional feeds
- Efforts should be directed toward cost-effective biorefinery processing

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Will *Saccharina latissima* reduce methane emissions in ruminants?

Low levels of red seaweed (e.g. Asparagopsis) containing bromoform can block methane production in the rumen

In vitro methane emissions using rumen fluid from lambs and dairy cows

Seaweeds could be a solution to reduce GHG emissions from red meat production