Alg'n Chem, Montpellier 1-3.April 2014

Bio-based products from cultivated seaweed biomass in a value chain approach

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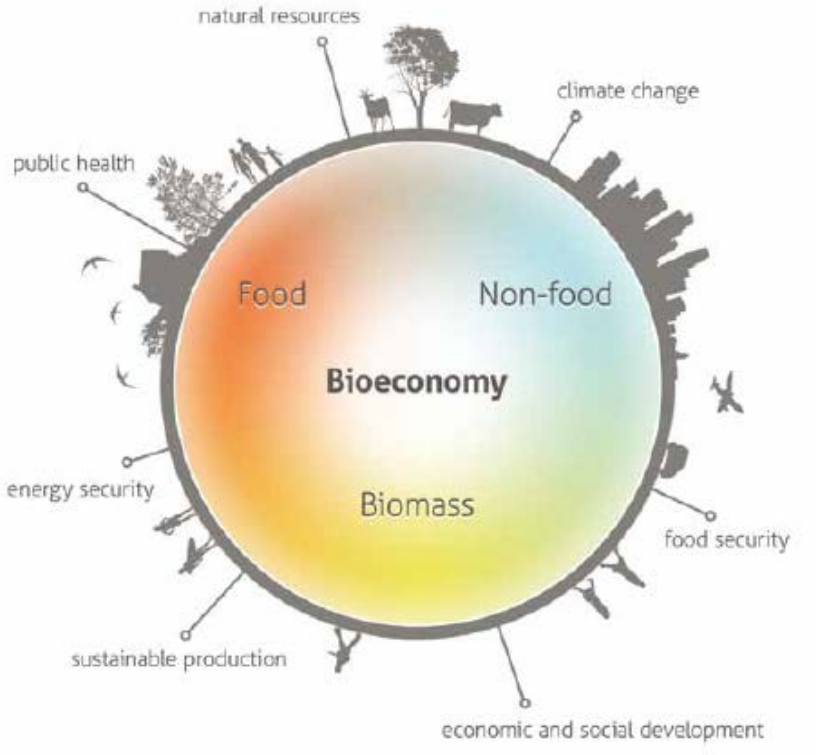
The trends in the bio-economy

"The bioeconomy encompasses the sustainable production of renewable biological resources and their conversion into food, feed, bio-based products and energy"

(European Commission, "Innovating for sustainable growth: A bioeconomy for Europe", 2012).



Biobased products: Marked potential

Global market: Feed additives (amino acids & enzymes) ~7 Mrd US$

Market for pre-treatment chemicals: 10 Mrd $ by 2020

- Bulk chemicals: ~25 Mrd $ by 2017
- Fine & Speciality Chemicals: EU 4 Mrd $; US 6 Mrd $, app 10 increase/a
- Bioplastics: US ~3 Mrd $

Energy: 15,5 TWh
US: 65 Mrd $ Heat & Power

Biofuels: 1,6 TWh (e.g. 70 Mm^3 bioethanol)

Total global market for Biorefinery value chain: ~300 Mrd $ by 2020

(SINTEF Priority Project: Bio-based products from sustainable resources)

Relevant product classes possibly derived from seaweeds

Food and pharma

Feed ingredients

Biochemicals

Fertilizers

Biofuels

Potential products and anticipated price from macroalgal species suited for cultivation in Norway

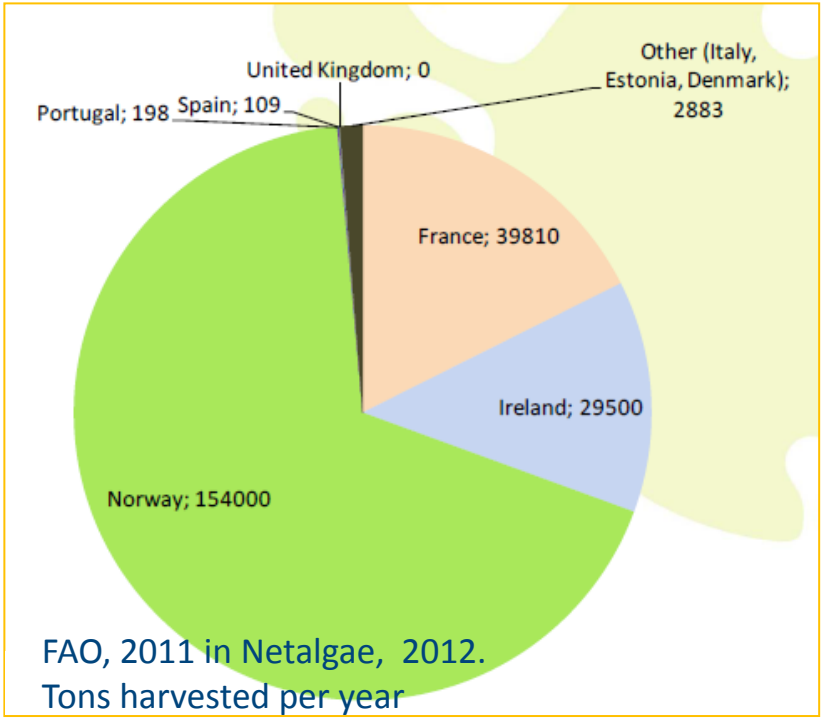
Compounds	Potential products and/or markets	Potential price*
Unprocessed plants	Food	Low-medium
Seaweed extracts	Cosmetics	Medium
Carbohydrates /	Thickening, viscosity enhancer etc.	Medium
polysaccharides	Prebiotics	Medium
	Pharmaceuticals	High
	Fermentation substrate (fuels, chemicals)	Low
Protein	Animal and fish feed	Low-medium
	Bioactive peptides (food/feed)	High
Polyphenols	Antioxidants (food/feed, cosmetics)	High
	Antimicrobials (food preservation, antifouling etc)	Medium-high
Ash	Fertilizer	Low-medium
	Valuable minerals	Medium-high

*: Low: < 1 Euro/kg; Medium: 1-10 Euro/kg; High: >10 Euro/kg

Seaweed industry in Norway

- 2 species harvested (*L.hyperborea* and *A.nodosum*)
- 2 companies
  - FMC Biopolymer: Alginate
  - Algea: Meal, bioactive extracts for feed, health food, cosmetics and fertilizers
- Economic value (2013): 150 Mill Euro
- Cultivation – new companies:
  - Algea
  - Seaweed Energy Solutions
  - Ocean Forest
  - Hortimare Norway
  - Ocean Future

Licences in 2014

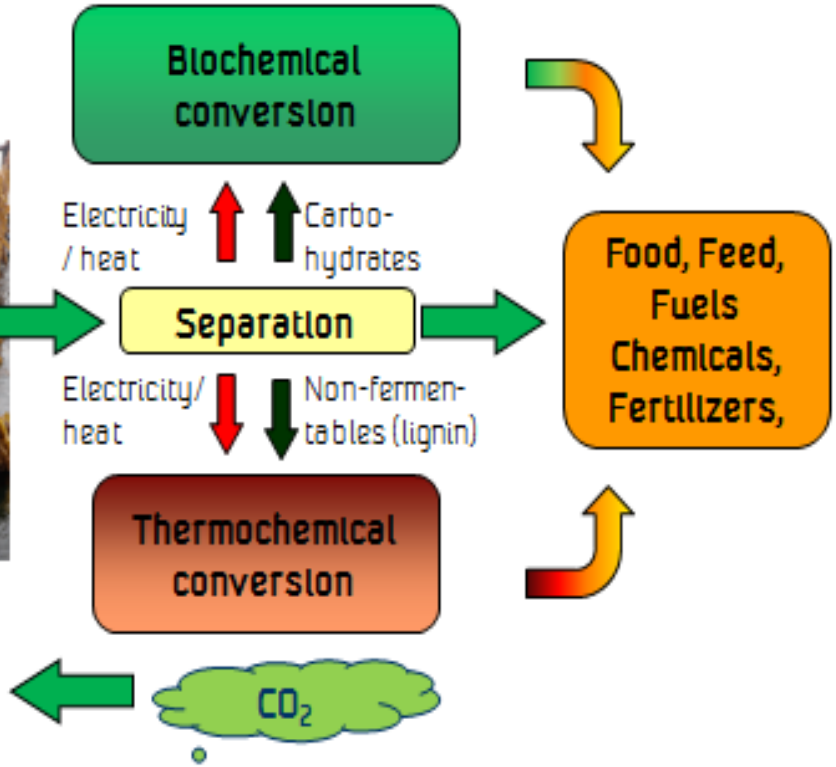


FAO, 2011 in Netalgae, 2012.
Tons harvested per year

Total in Europe: 226 500 tons

Cultivated: 0,1%

The value chain for cultivated seaweed

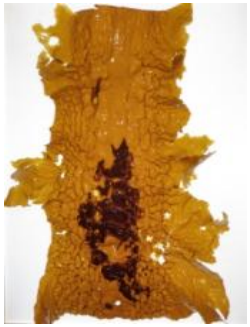


Why cultivated biomass?

- Attractive biomass (composition affected by season and age)
- Sustainable production of biomass, no (known)negative effect on the benthic ecosystem
- Large volumes possible
- Effective harvesting and freshness of biomass
- Possibilities for nutrients recycling (IMTA)
- Wide range of species (480 in Norway)

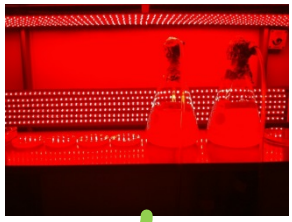
Seedlings production – Sugar kelp *Saccharina latissima*

Step 1: Induction of sorus (6-12 weeks)



Step 2: Dehydration and spore release (24 h)

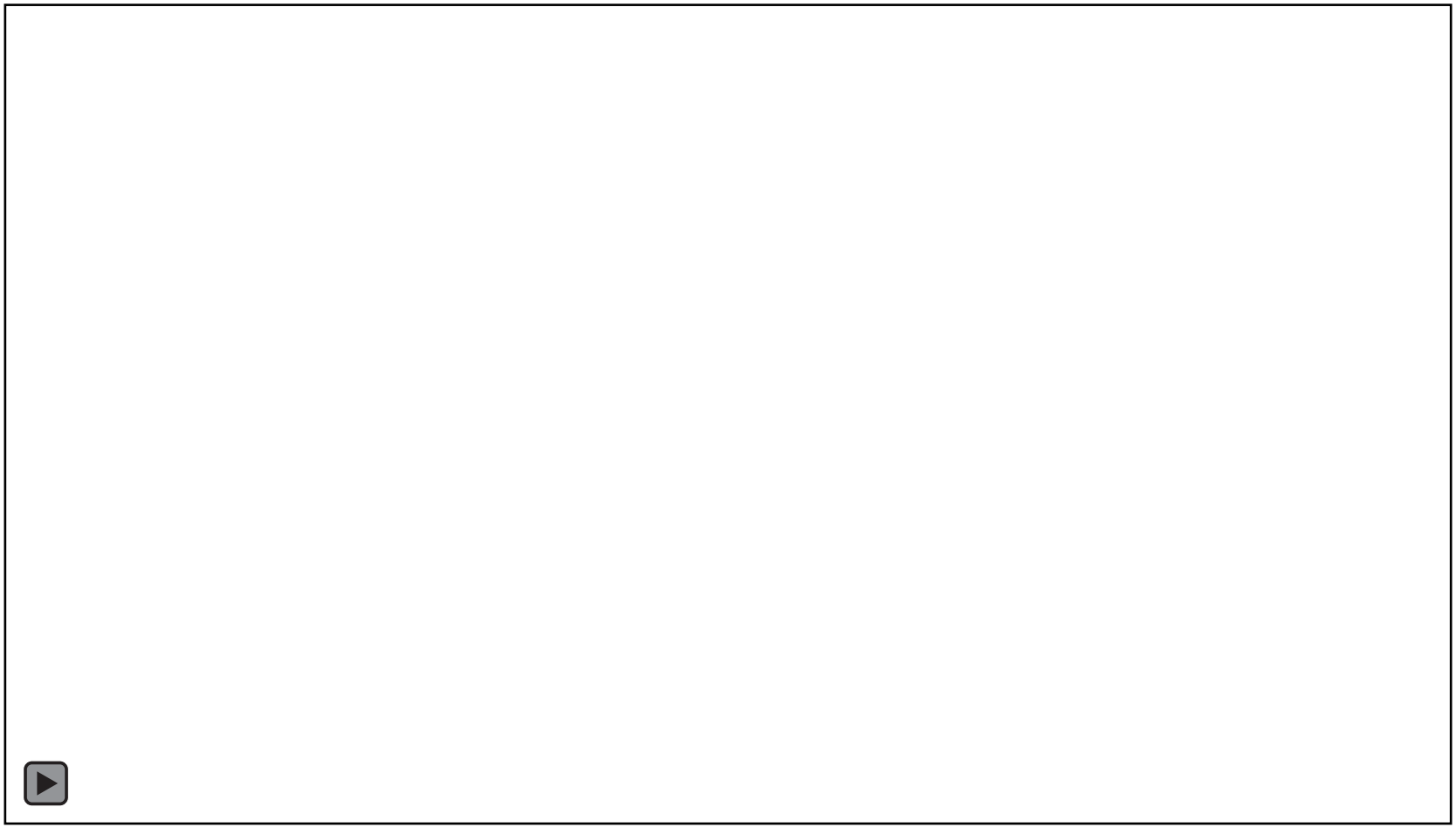
Gametophyte cultures



Step 3: Spraying and incubation (~ 2 months)

Forbord, S. et al. 2012. Development of *Saccharina latissima* (Phaeophyceae) kelp hatcheries with year-round production of zoospores and juvenile sporophytes on culture ropes for kelp aquaculture. *Journal of Applied Phycology,* 24 (3), 393-399.

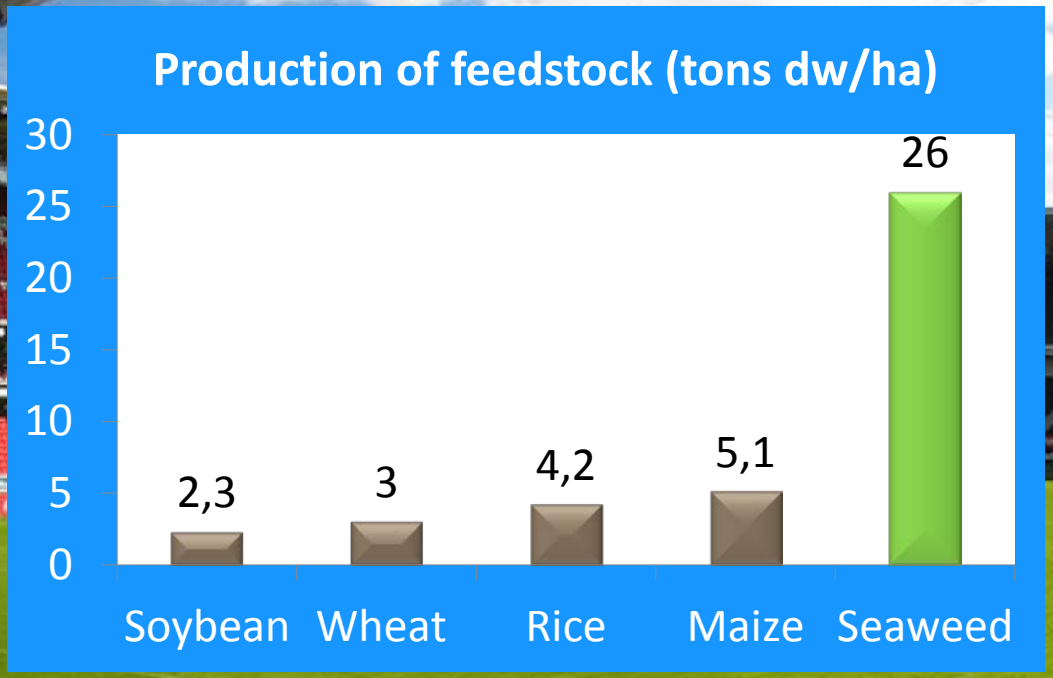
Technology development – prototyping



Productivity *S. latissima*:

170 tons ha^{-1} $year^{-1}$

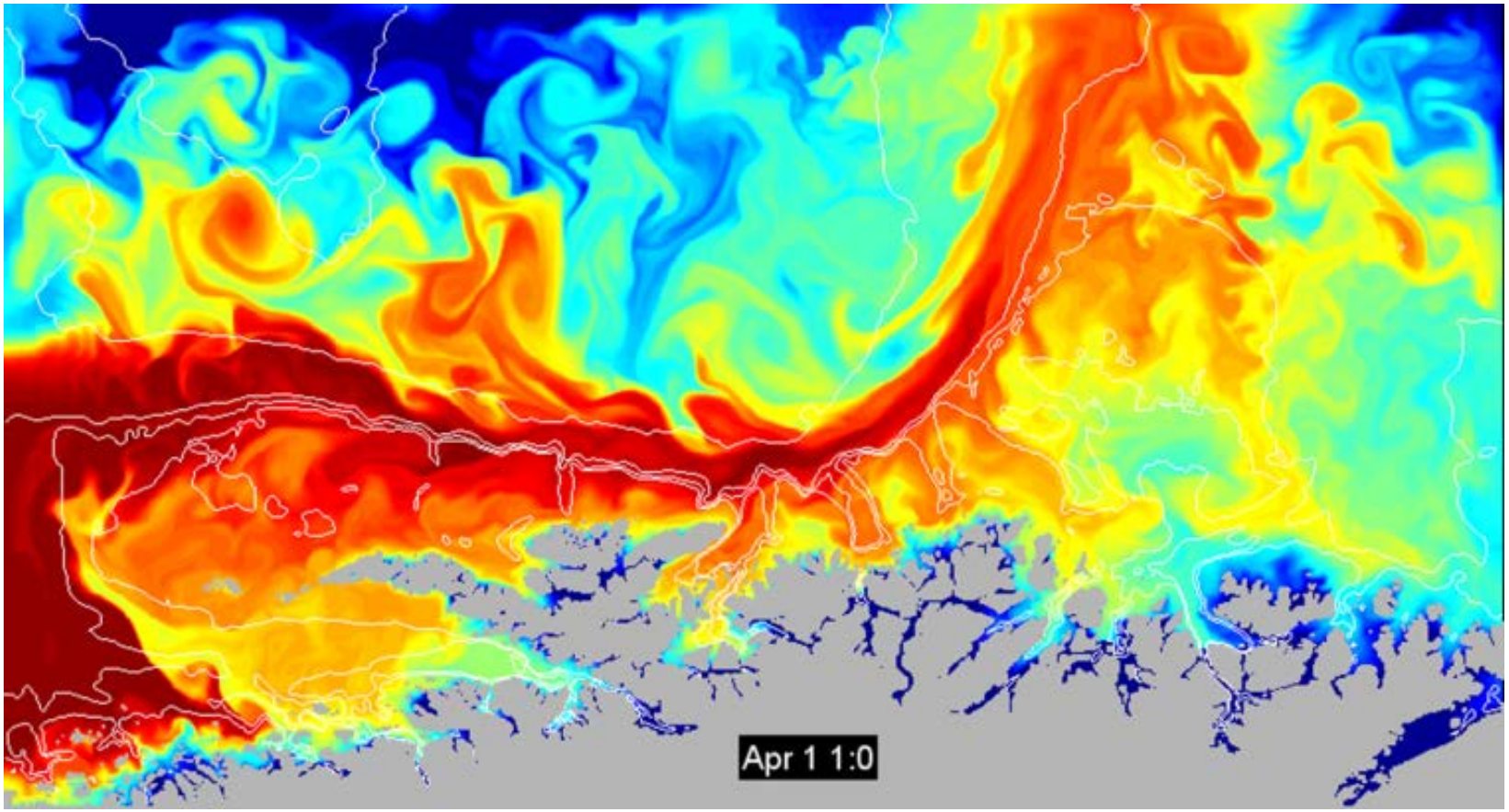
~ 1 hectar



- 170 tons ww
- 26 tons dw
- 15 tons carbohydrates
- 3.8 tons protein

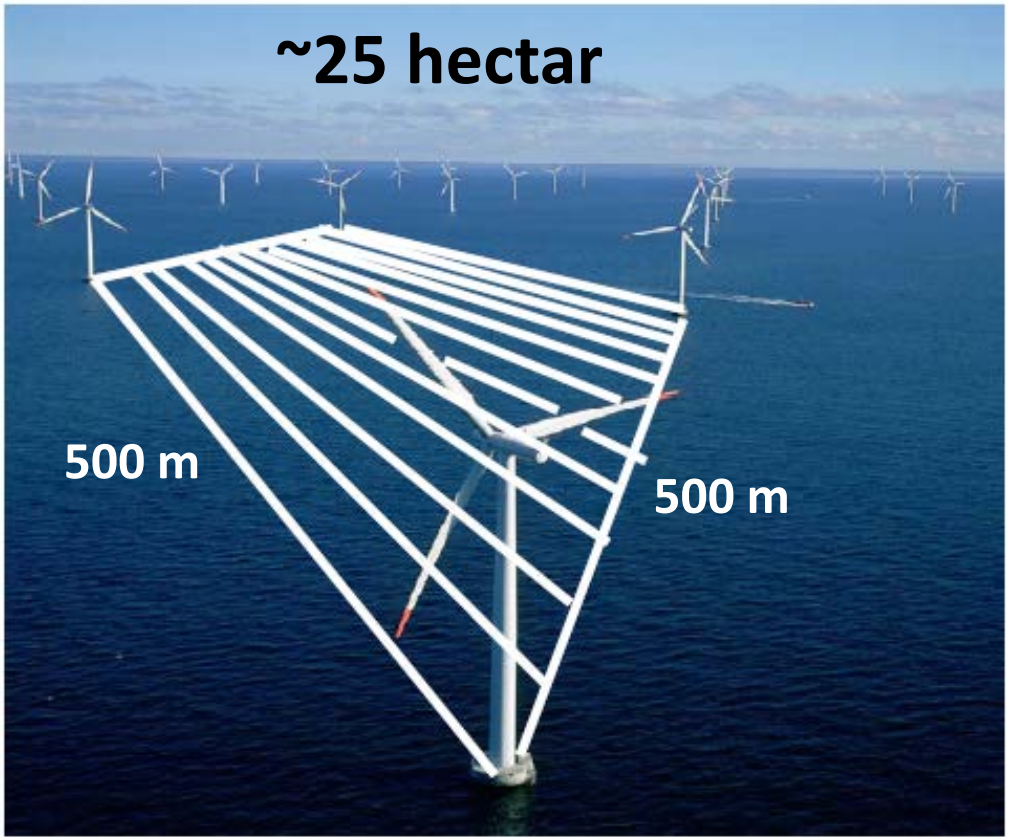
Are there available areas?

High productive areas?



Broch et al., 2013. Modelling the cultivation and bioremediation potential of the kelp *Saccharina latissima* in close proximity to an exposed salmon farm in Norway. *Aquaculture Environment Interactions* 4, 187-206.

Infrastructure and area use



- 4 250 tons ww sugar kelp
  - 380 tons carbohydrates
  - 95 tons protein

Nutrient mass-balance budget for salmon aquaculture

Feed
(100% N)
(100% P)

Integrated multi-trophic aquaculture (IMTA)

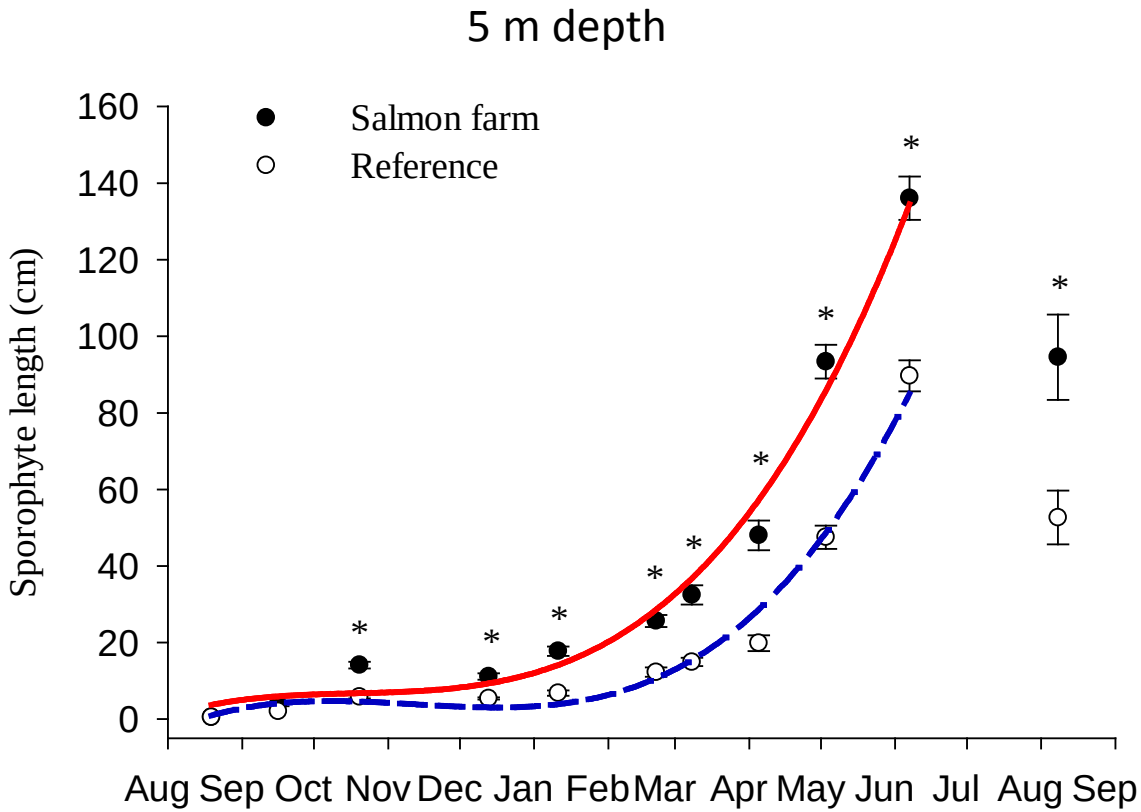
Particulate nutrients
(~15% N)
(~44% P)

Fish
(N~40%)
(P~35%)

Dissolved nutrients
(~45% N)
(~18% P)

Wang et al., 2012. Aquaculture and Environment Interactions, *2:267-283*

Growth of S. *latissima* in IMTA with *Salmo salar*



Reference

Salmon farm

Handå, A. et al., 2013. Seasonal- and depth-dependent growth of cultivated kelp (*Saccharina latissima*) in close proximity to salmon (*Salmo salar*) aquaculture in Norway. *Aquaculture* 414-415, 191-201.

Cultivation strategies

- Seasonal effects
  - Chemical composition and bio-fouling
  - Timing and method for seeding and harvesting

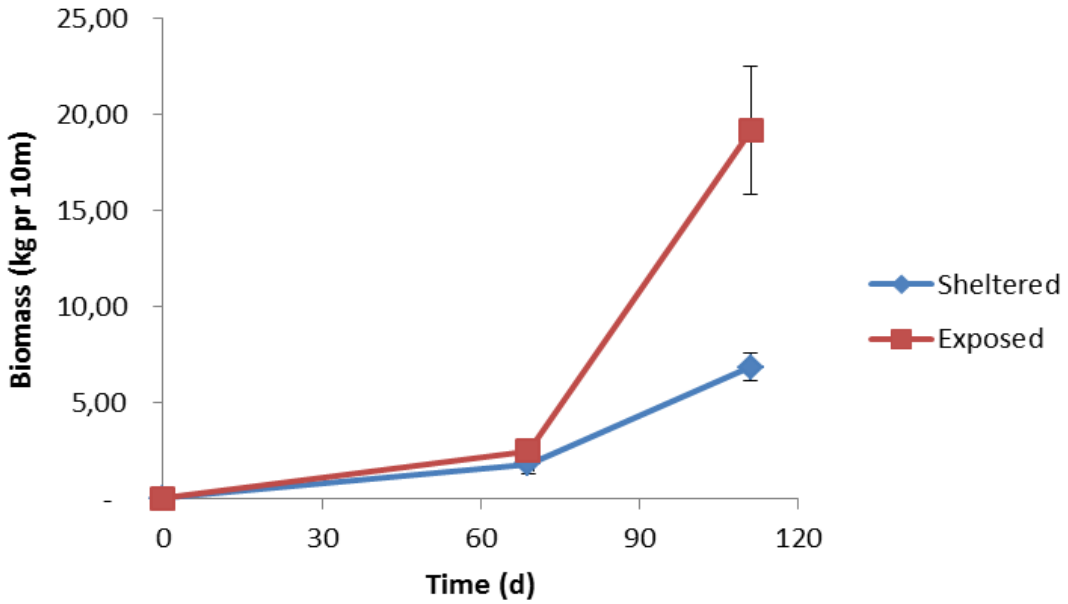
June

August

Cultivation strategies

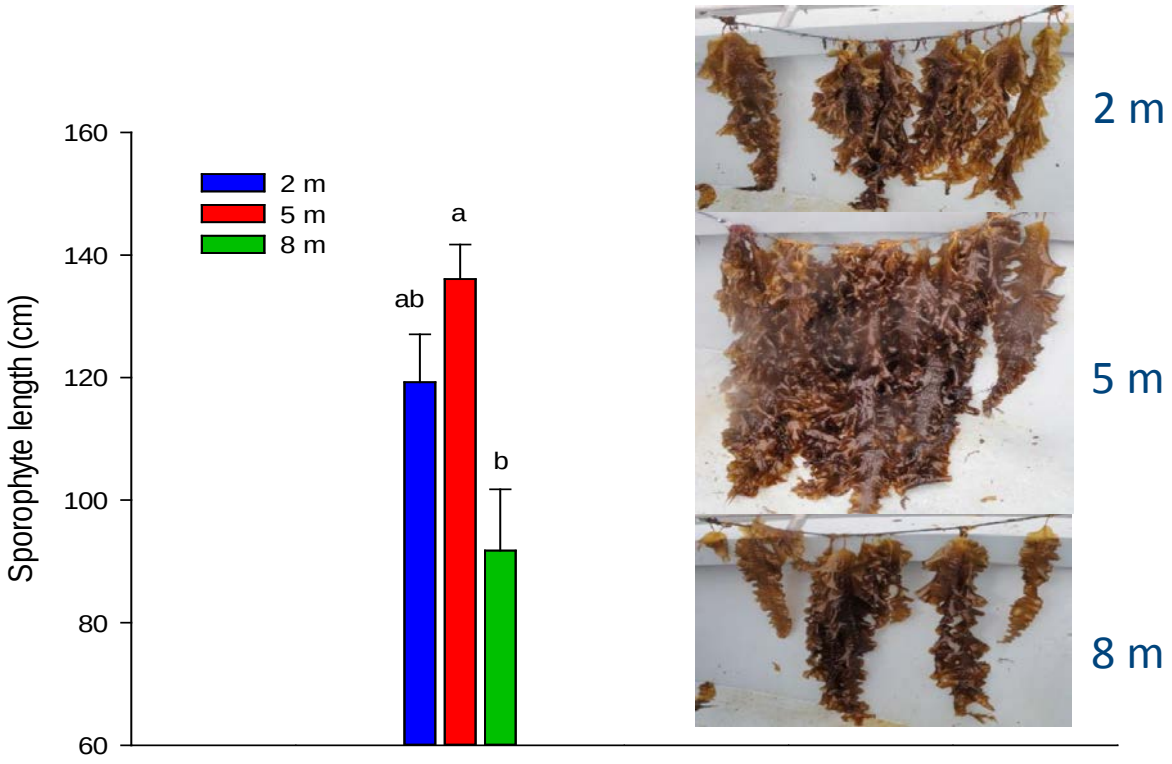
- Environmental conditions
  - Water currents and waves

Effect of water currents on *S. latissima*:



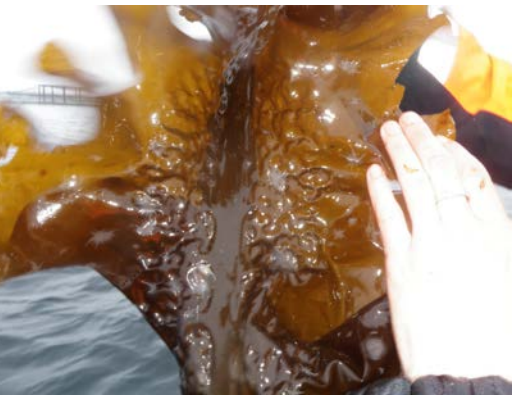
Cultivation strategies

- Environmental conditions
  - Light and depth



Cultivation strategies

- Species
  - Large brown kelps for biomass production
  - Smaller species for high value components



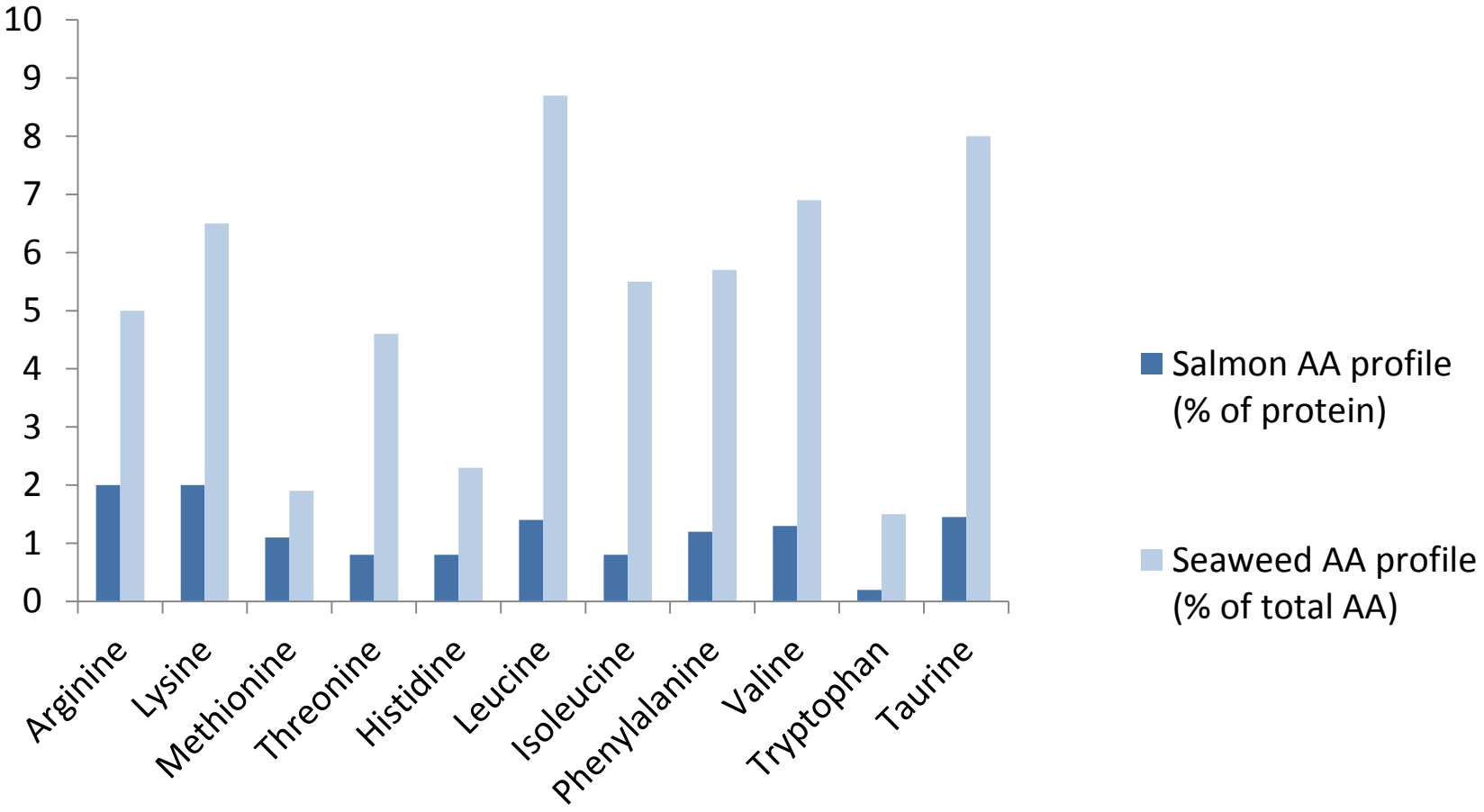

Application for nutrients and energy (brown, red and green species)

- Dry matter (6-39%)

- Nutrients
  - Proteins and amino acids (17-44%)
  - Bioactive components: fucoidan, fucoxanthin, laminaran (β-1,3 glucan), mannitol, alginic acids and high-M alginate, ulvan
  - Pigments, antioxidants, vitamins and minerals
  - Lipid levels are low (up to 4.5%)
  - Polyphenols

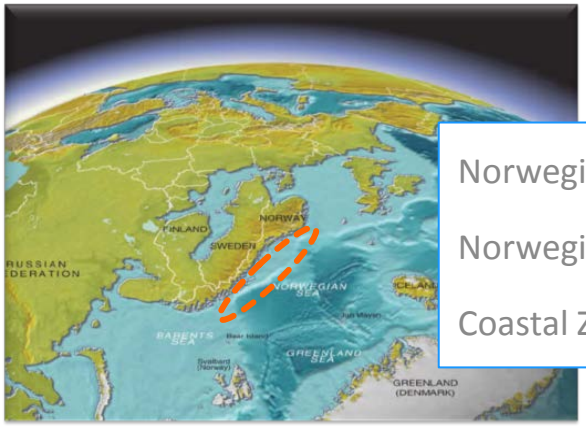
- Energy
  - Carbohydrate fraction (up to 60%)

Sugar kelp as protein source for salmon feed



Ethanol yield from cultivated kelp

Production potential in Norway?



Norwegian coast line: 103.000 km

Norwegian Economical Coastal Zone: 788.000 km^2

Coastal Zone within Sea boundary: 89.000 km^2

- Presently Norwegian salmonid aquaculture produces 1.3 million tons yr^{-1} using **800 km^2**
- Using a **similar area** for macroalgae cultivation:

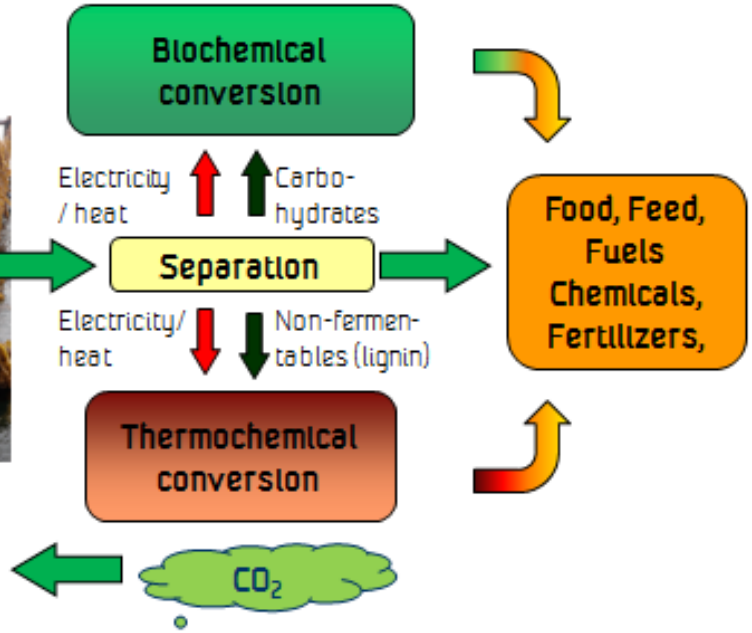
↓

- **470.000 tons ethanol (= ca 50% of todays gasoline consumption)**

A "new" bioeconomy based on cultivated seaweed

Focus needed on:

- Biomass production
- Biorefinery
- Species diversification and product quality optimization



The SINTEF Priority Project (2013-16):

"Bio-based products from sustainable sources"

- **Technology goals**
  - Establish predictable and efficient seaweed production
  - Develop high dry mater / minimum diluted pre-treatment process(es)
  - Develop thermochemical processes operating at 80% water
  - Production of value added bioproducts
  - Novel separation sequences
  - Develop catalytic processes to operate in aqueous phase
  - Develop high energy solid fuel
  - Integrate thermochemical and biochemical conversion technologies in order to optimize the overall process
  - Evaluate the feasibility of the processes through techno-economic studies
- **Framework goals**
  - Improve current framework for implementation of bio-based products
  - Improve cooperation between major Norwegian stakeholders
  - Coordinate engagement in strategic and policy aspects (national & international)

Thank you for your attention!

Please contact us for more information and possible collaboration:

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