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Macroalgae harvesting and cultivation

macroalgae in the Baltic Sea, system design, technology, and application practices in the region

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Algae – definition

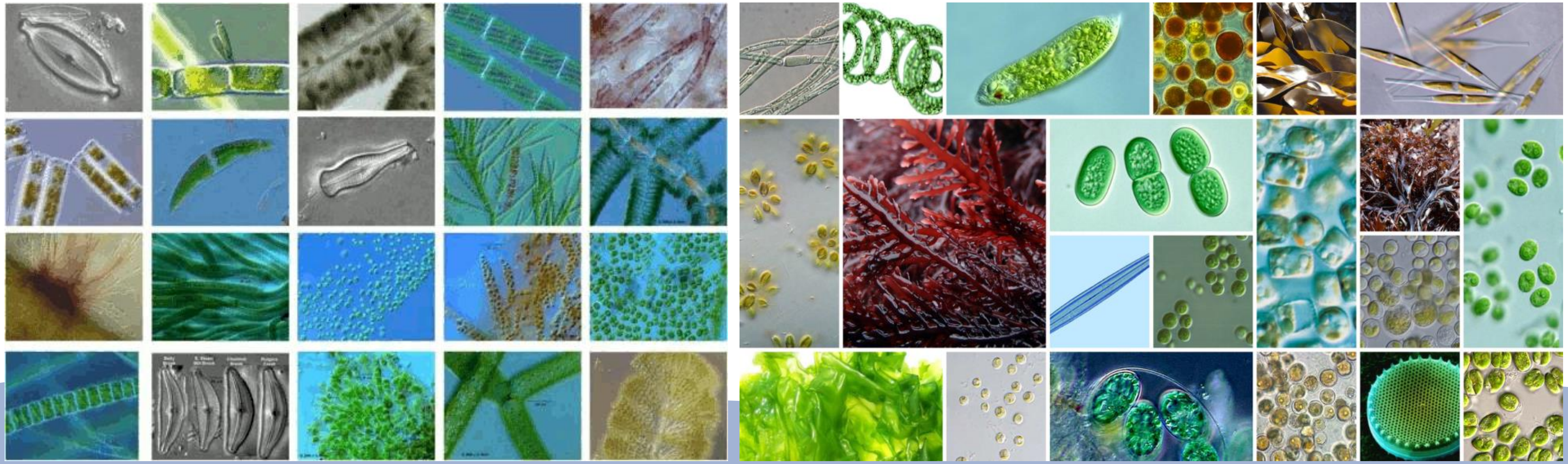
AlgaeBase

alga ← eukariotic, water, chlorophyll, photosynthesis

multicellular marine alga = seaweed

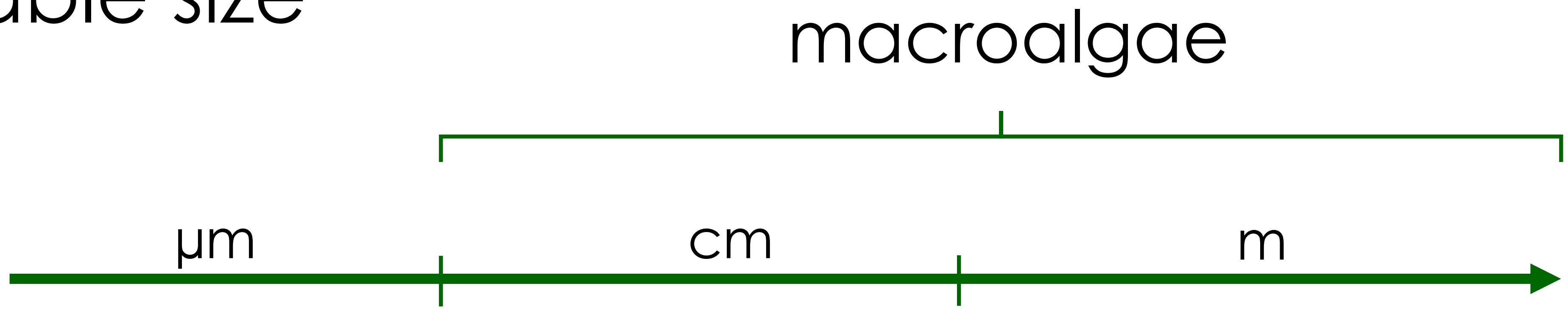
Macroalgae – characteristic

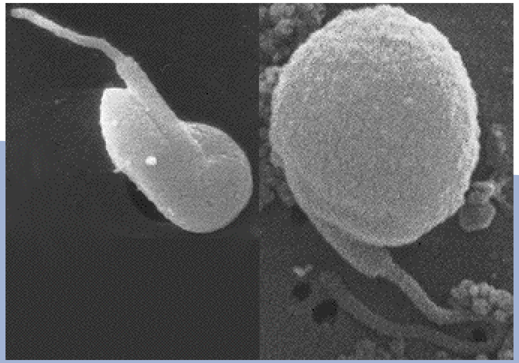
unicellular and multicellular



Macroalgae – characteristic

variable size





Micromonas pusilla

Valonia ventricosa

Macrocystis pyrifera

Macroalgae – characteristic

various pigments apart from chlorophyll

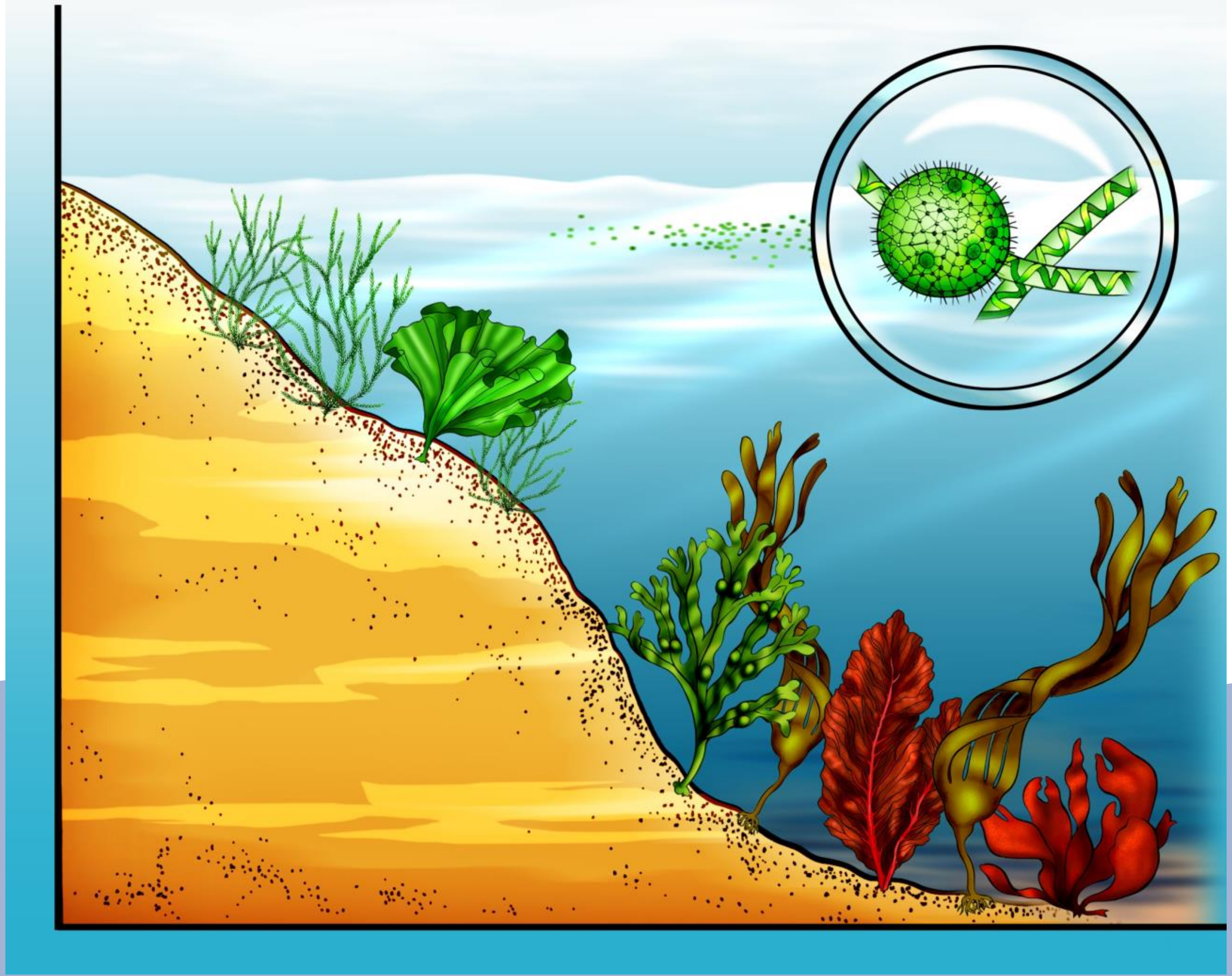
Green algae
Chlorophyta
opportunistic species in eutrophic waters
over 1800 species
Ulva, *Caulerpa*, *Chaetomorpha*

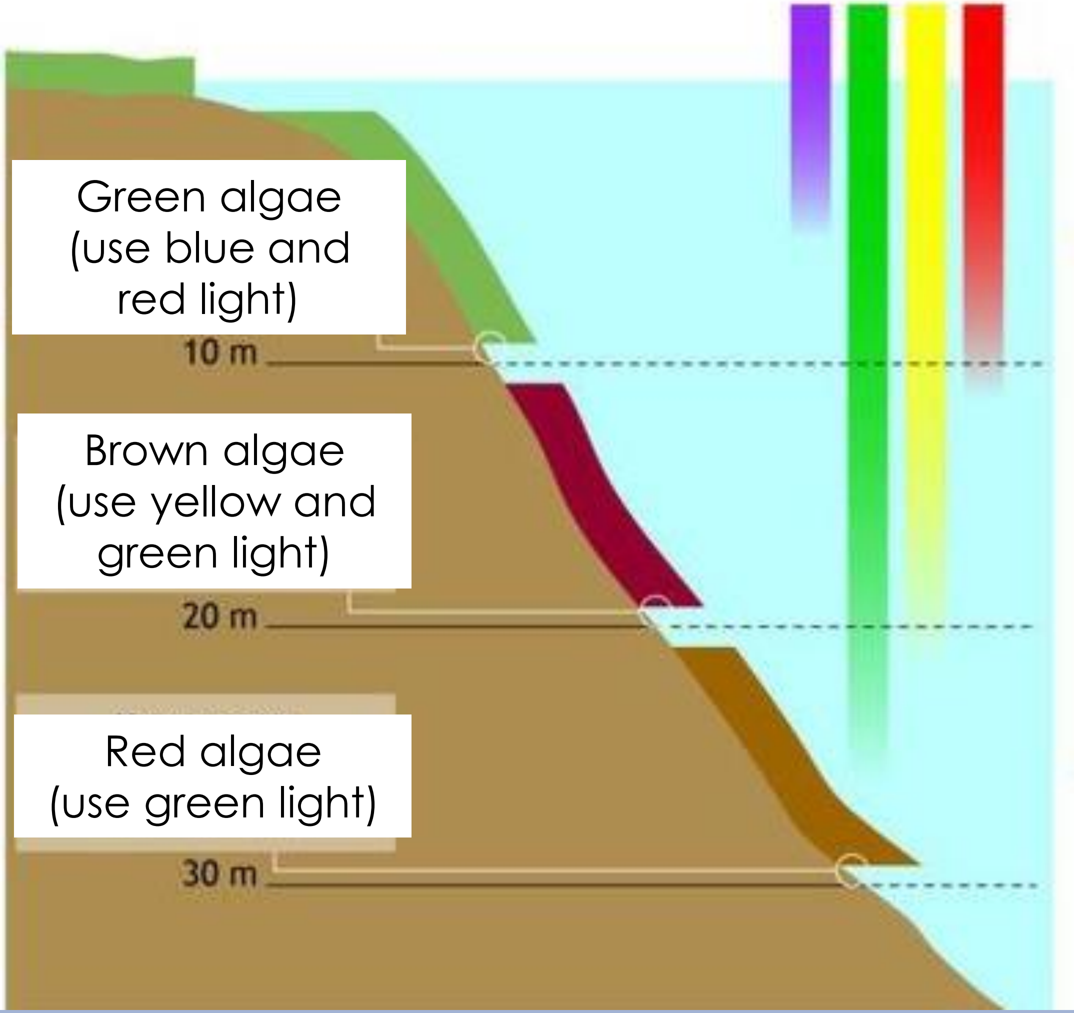
Brown algae
Phaeophyceae (kelps & wracks)
2000 species
typical for cold waters *Laminaria*, *Saccharina*, *Fucus*

Red algae
Rhodophyta
over 6500 species
mostly marine
Palmaria, *Gracilaria*, *Chondrus*

Macroalgae – characteristic

zonation in seas





Macroalgae – characteristic

... potential of macroalgae

- high photosynthesis level (algae incl. phytoplankton - 90% of O_2 and 80% of organic matter)
- high growth rate e.g. max 0,5 m day^{-1} (2-14 kg per $m^{-2} yr^{-1}$)
- high levels of nutrient uptake, reduction of CO_2 and heavy metals

Macroalgae – characteristic

... potential of macroalgae

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Macroalgae – characteristic

... potential of macroalgae

- habitat forming
- source of organic matter in aquatic ecosystems
- source of food & feed, biomolecules, fertilisers, new materials, ..., aesthetic needs




Macroalgae – Baltic Sea

... but week tradition of exploitation
and no tradition of cultivation in the Baltic

... before 1940's

Macroalgae – Baltic Sea

Industrial exploitation of *Furcellaria lumbricalis:*

- Denmark – the mid 1940s until the mid 1960s
- Poland – 1963 – 1972
- Estonia – early 1960s untill now




Macroalgae – Baltic Sea

- increased interest in macroalgae since the 1980s (first pilot studies)
- the beginning of the development of aquaculture since the mid-2010s

Macroalgae – Baltic Sea

- strongly affected by salinity gradient – reduction of distribution, dwarfed forms
- unsuitable type of substrate
- number of macroalgae ??? 300-400 max.
- potential for new introductions – relatively young sea with habitats under recovery

Weinberger et al. 2019, Botanica Marina 63(1): 61–72

Macroalgae – Baltic Sea

Other challenges:

- ice cover in winter
- lack of legal conditions and complicated permit/license proces (not specific EU legislation as well)
- lack of expert knowledge
- need for technological development

More findings on GRASS project webpage: …

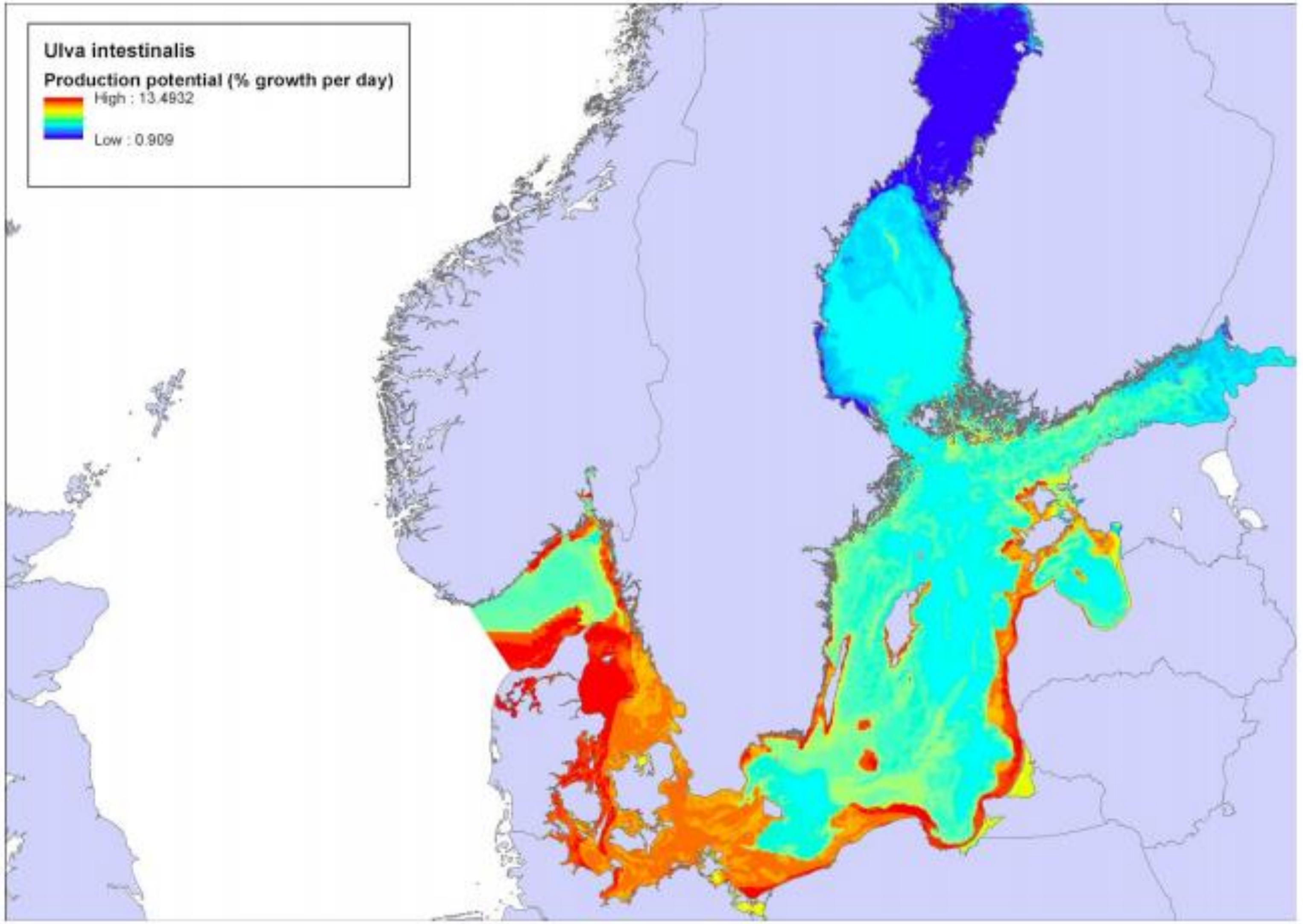
Baltic green algae

Ulva spp.

- distribution – entire BS
- growth rates can be five times faster than that of corn
- potential for **nitrogen bioremediation (deeutrophisation)** of waters and **biofuels production**
- potential of cultivation tested in a number of countries
- projects: TANG.NU, SeaSus-protein, GRASS

Baltic green algae

Ulva intestinalis



Kotta et al. 2020

Baltic green algae

The most significant findings regarding *Ulva* sp.:

- can be **harvested from green-tides** („habitat restoration", Denmark ca. 10 t yr^{-1}), machine harvesting
- **manual harvesting** for high-end users (Norway, Denmark)

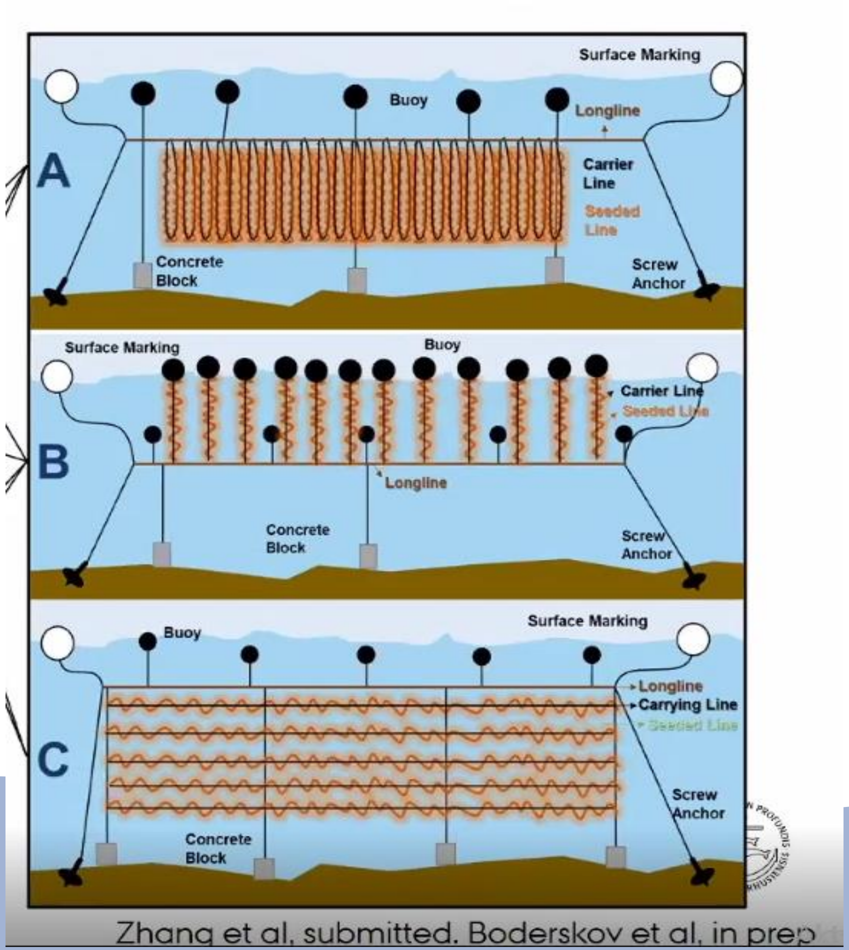
Bruhn et al. 2020, Araujo et al. 2021

Baltic green algae

The most significant findings regarding *Ulva* sp.:

- cultivation in coastal waters sucessful only **on ropes** (Denmark - 1 t yr^{-1}, Sweden)

Christiansen 2018



Bruhn et al. 2020, Araujo et al. 2021

Baltic green algae

The most significant findings regarding *Ulva* sp.:

- cultivation in various **nutrient rich waters** (manure, waste waters, RAS)(Denmark, Norway, Sweden)
- recommendation of avoiding cultivation or harvesting of *Ulva* from industry **contaminated areas**

Nielsen et al. 2012, Sode et al. 2013, Christiansen 2018, Bruhn et al. 2020, Araujo et al. 2021

Baltic green algae

aqua VIP

Dyrk din egen søsalat

A) Find søsalat

Gå evt. ind på www.vildmad.dk og søg på søsalat under "råvarer" for at finde informationer om forekomster og kendetegn.

(?) Hvordan kendetegnes søsalat?

◯ Det ligner lidt salatblade

◯ Det er grønt og gror i søer

C) Vask og forbered søsalat

Skyl søsalaten under hanen til du har et rent "salatblad". Klip små stykker (0.5*0.5cm) af siderne af og brug dem i **D**.
Hint: klip små stykker fra flere forskellige søsalatsblade.

(?) Hvorfor skylle søsalaten?

◯ Så det kun er søsalat, der gror

◯ For at fjerne alt saltet

Inden fjerde skift skulle du kunne se baby-søsalat begynde at gro

E) Skift kunstigt havvand ca. hver 2. uge

Første gang vandet skiftes kan søsalaten fra **D** smides ud. Fra nu af vil søsalaten gro op fra snoren og siderne på glasset.
Hint: Ryst glasset blidt en gang om dagen.

(?) Hvorfor skal det kunstige havvand skiftes jævnligt?

◯ For at sørge for, at der hele tiden er nok salt og næring

◯ For at forhindre små fisk i at spise de nye spire af søsalat

Intet grønt ved 4. skift?

Dette kan være årsagen:

- *For lidt/meget lys*
- *Ikke anvendt havsalat*
- *Succesraten er størst i foråret.*

B) Fremstil kunstigt havvand

20 g. HAVsalt blandes om i 1 L vand og blandes grundigt. Gødning tilføjes saltvandet ud fra instrukserne på pakken. Opbevar på køl.
Hint: Giv vandet dobbelt så meget gødning som anvist.

(?) Hvorfor bruge kunstigt havvand?

◯ Fordi det vokser bedst i søvand

◯ Fordi det er renere end rigtig havvand

D) Start dyrkning

Kom 30 cm snor ned i et syltetøjsglas. Fyld glasset med kunstigt havvand fra **B** og smid de vaskede stykker søsalat ned i glasset. Henstil i et vindue overtrukket med film.
Hint: Er der ikke nok lys i dit vindue? Stil en lampe over den og hav den tændt, når du er hjemme.

(?) Hvor gror søsalat bedst?

◯ Hvor der er meget lys og høj næring

◯ Hvor der er middel lys og lidt næring

◯ Det vides endnu ikke helt! Dyrk søsalat og vær med i forskningen!

Er det lykkedes?
Send mig et billede!

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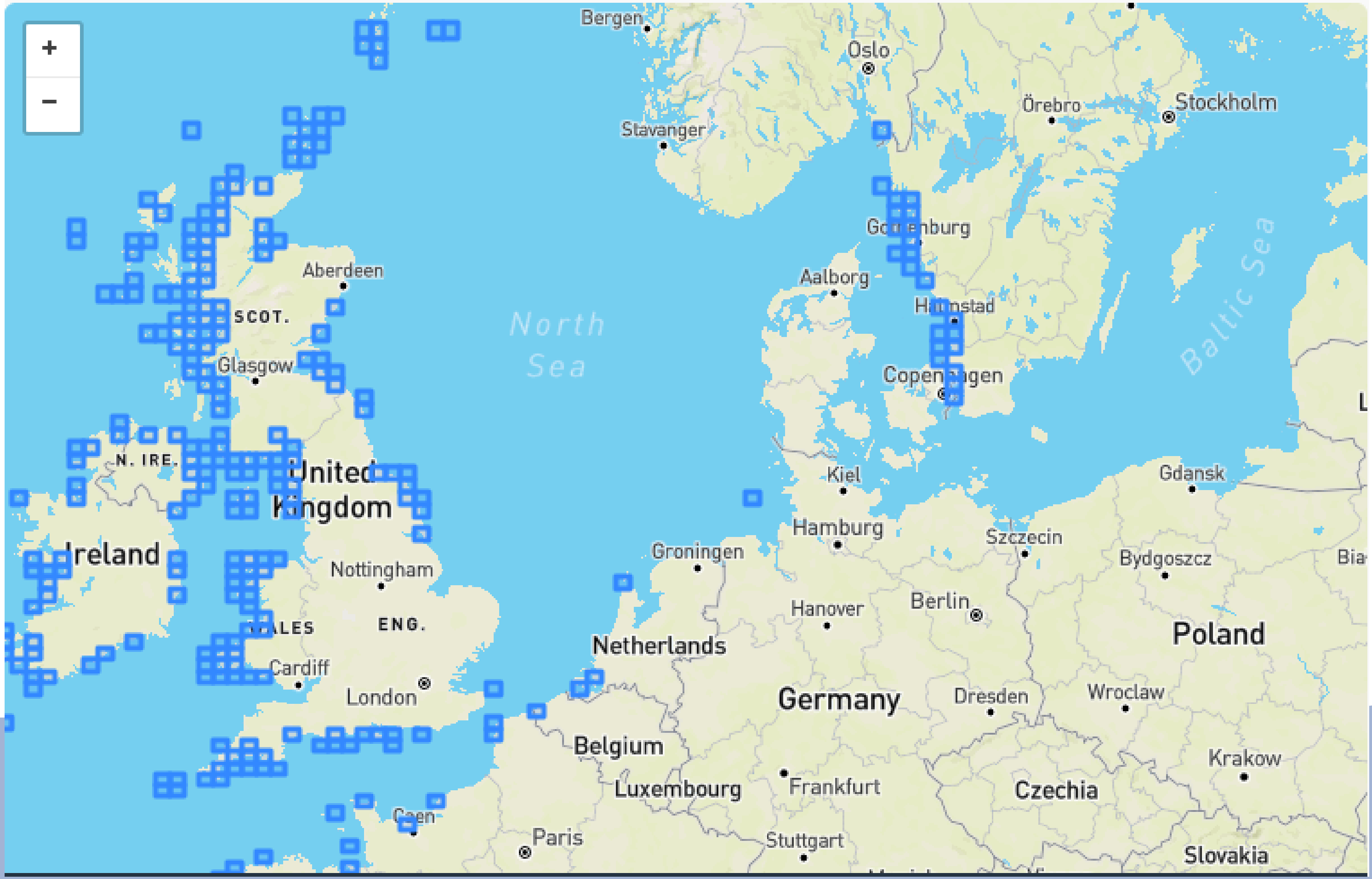
Christiansen E.R., 2018, The Potential of Ulva for Bioremediation and for Food and Feed, Msc thesis, DTU and AU, Denmark

Baltic brown algae

Saccharina latissima
Sugar kelp

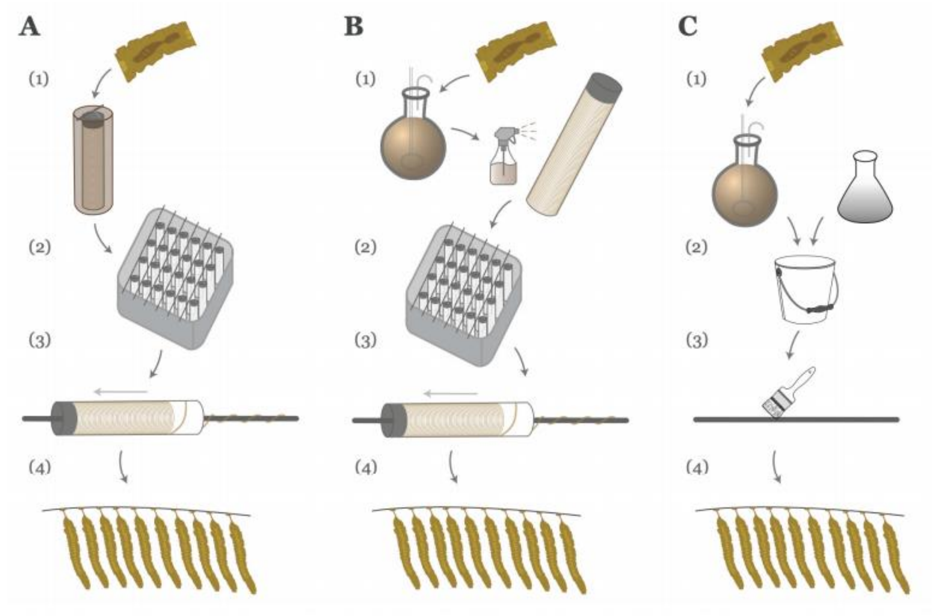
Salinity preferences:
full (30-40 psu), <u>down to 10 (survival)-13 (growth)</u>
Site preferences:
hard substrata such as rocks and boulders



https://www.marlin.ac.uk/species/detail/1375

Baltic brown algae

Saccharina latissima



- distribution **limited by salinity** (Bornholm)
- regarded as N and P reducer
- production CO_2 negative
- grown on lines or nets
- well described aspects related to culturing

Visch 2019, PhD thesis, Sustainable Kelp Aquaculture in Sweden, University of Gothenburg

Weiberger et al. 2019, Bruhn et al. 2020, Araujo et al. 2021, Bordrskov et al. 2021a, 2021b

Baltic brown algae

Saccharina latissima

- **commercial sea-based aquacultures** in: Denmark (7 locations) and Germany (1 location in tanks), Norway
- the largest farm in Denmark 10 t (ww) in 2014, < 16 t in 2020
- Nordic Seafarm (Sweden, Skagerrak) 20 t, Lerøy Ocean Harvest (Norway) 2016 - 17 t, 2017 - 40 t, 2018 - 100 t, but 1000 in perspective

Weiberger et al. 2019, Bruhn et al. 2020, Araujo et al. 2021, Boderskov et al. 2021a, 2021 b

Baltic brown algae

Saccharina latissima

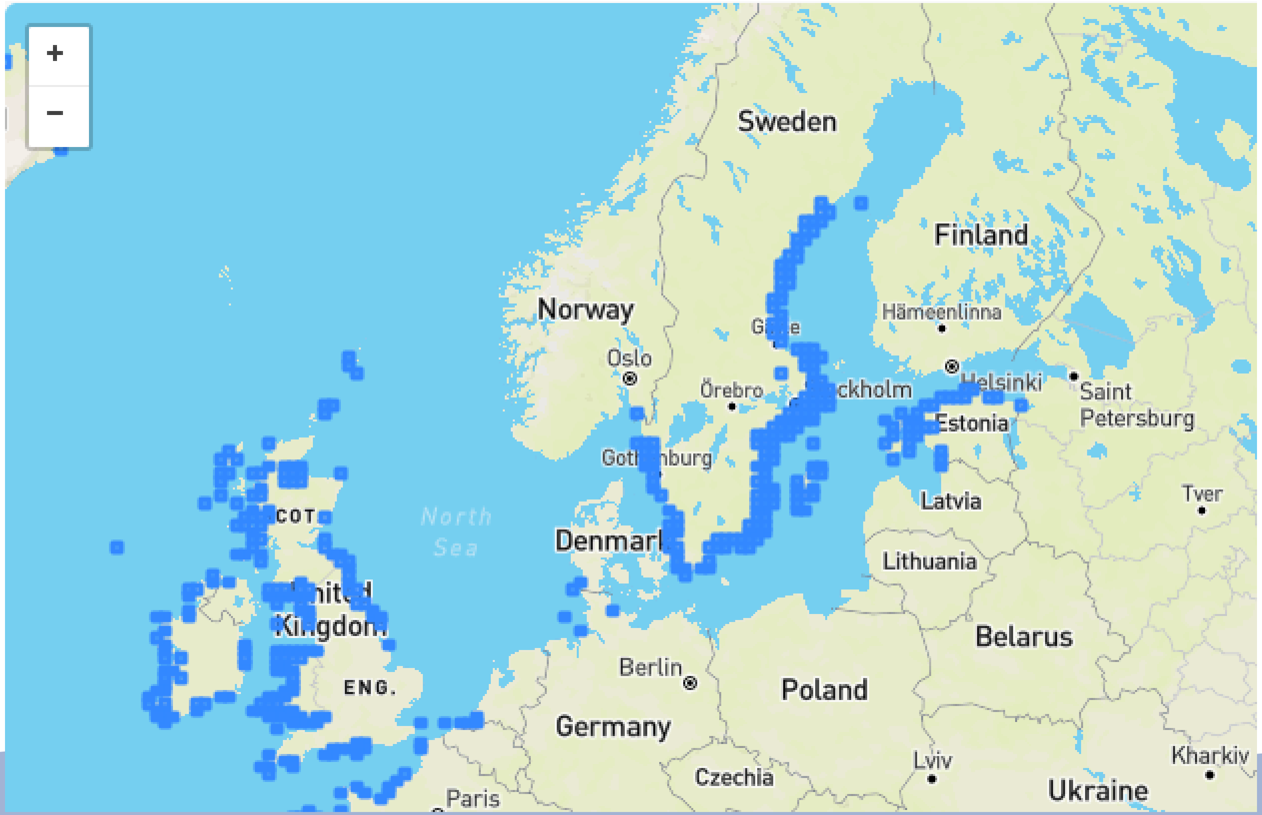
- projects: Seafarm (Sweden), Algae against cancer (Germany), MACROSEA (Norway)

Baltic brown algae

Fucus vesiculosus
Bladder wrack

Salinity preferences:
full (30-40 psu), reduced (18-30 psu), variable (18-40 psu), <u>down to 3</u>

Site preferences:
artificial (man-made), bedrock, cobbles, gravel / shingle, large to very large boulders, pebbles, small boulders

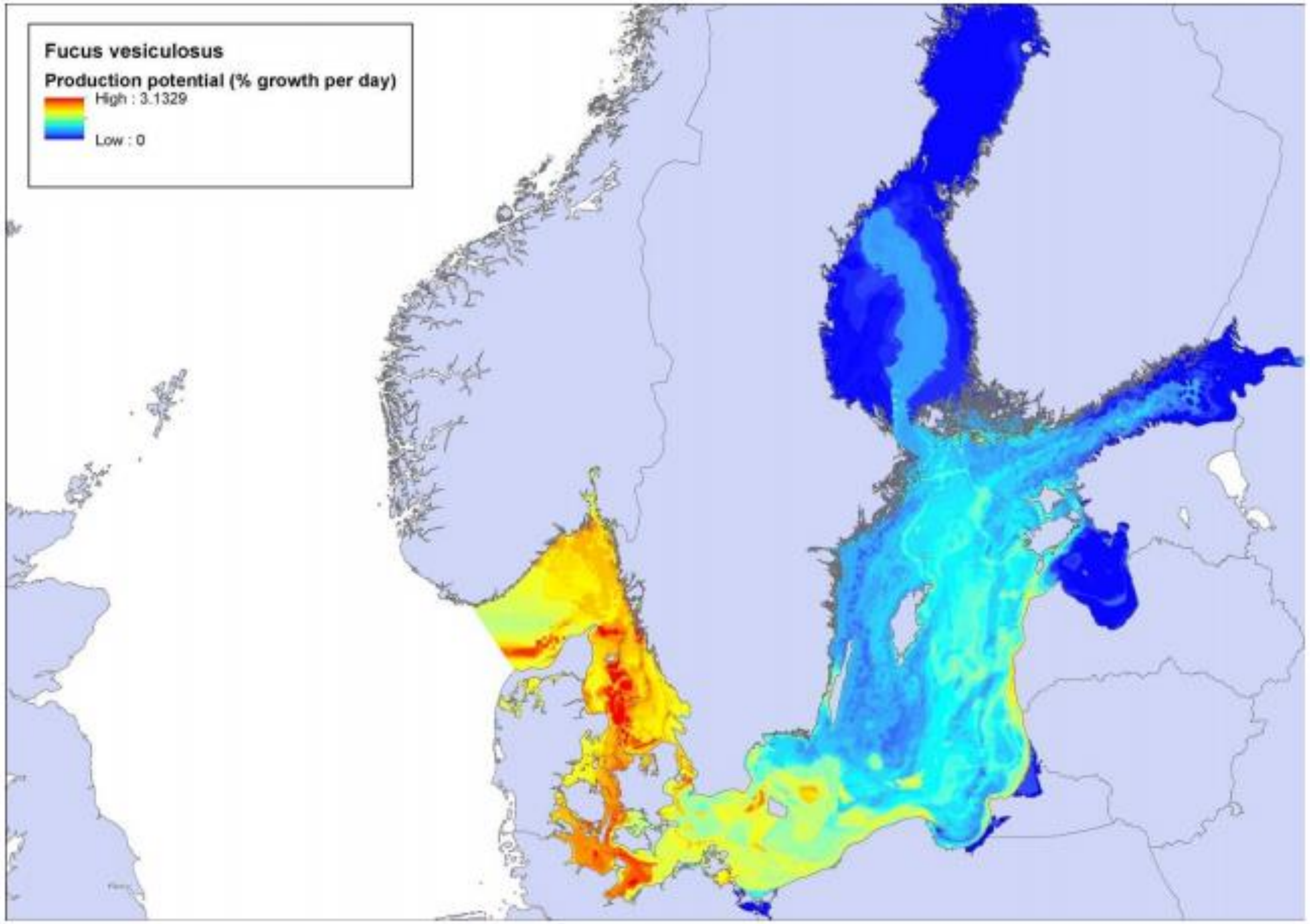


https://www.marlin.ac.uk/species/detail/1330

Baltic brown algae

Fucus vesiculosus
Bladder wrack

- new records in Poland in the Puck Lagoon



Kotta et al. 2020

Baltic brown algae

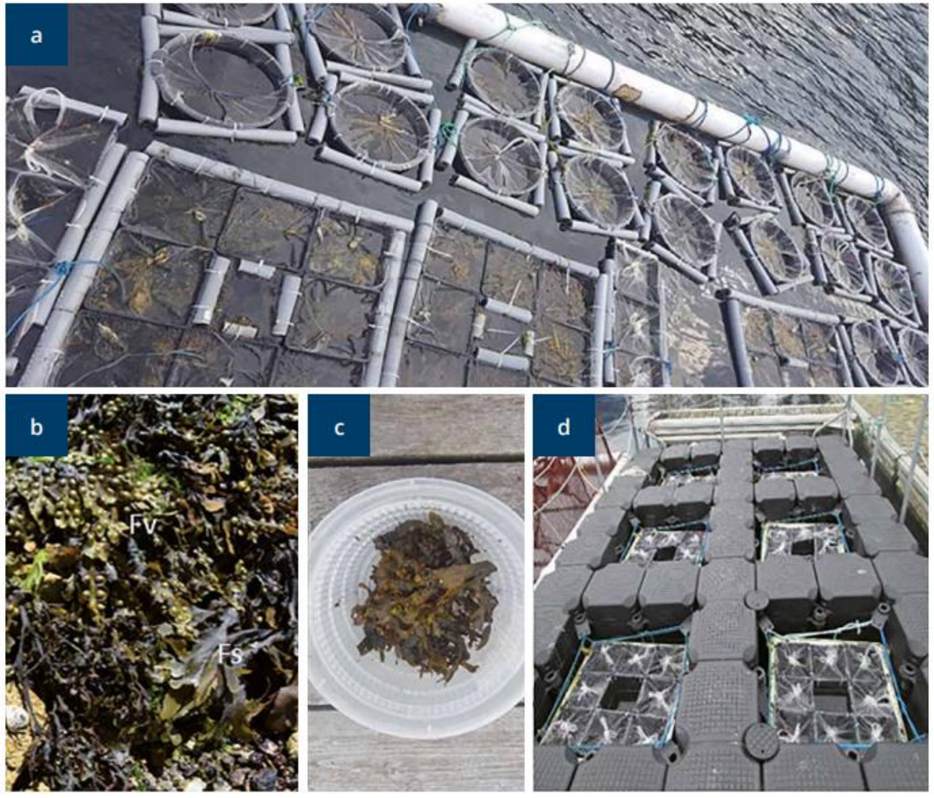
Fucus spp.

- **harvesting licence** - Organic Seweed in Denmark (10% of the standing stock per year), <1 t yr^{-1}
- experimental harvesting in Germany within FucoSan Project
- recommended harvesting – cut above bladders

Fucosan, 2017-2020, Result Report Algae sources, cultivation and collection, https://www.submariner-network.eu/macro-algae-topic

Baltic brown algae

Fucus spp.



- **cultivation** within FucoSan Project in Germany showed **it is possible and can be profitable**
- not cultivated in Denmark at present
- well described extraction methods

Fucosan, 2017-2020, Result Report Algae sources, cultivation and collection, https://www.submariner-network.eu/macro-algae-topic

Baltic brown algae

Fucus spp.

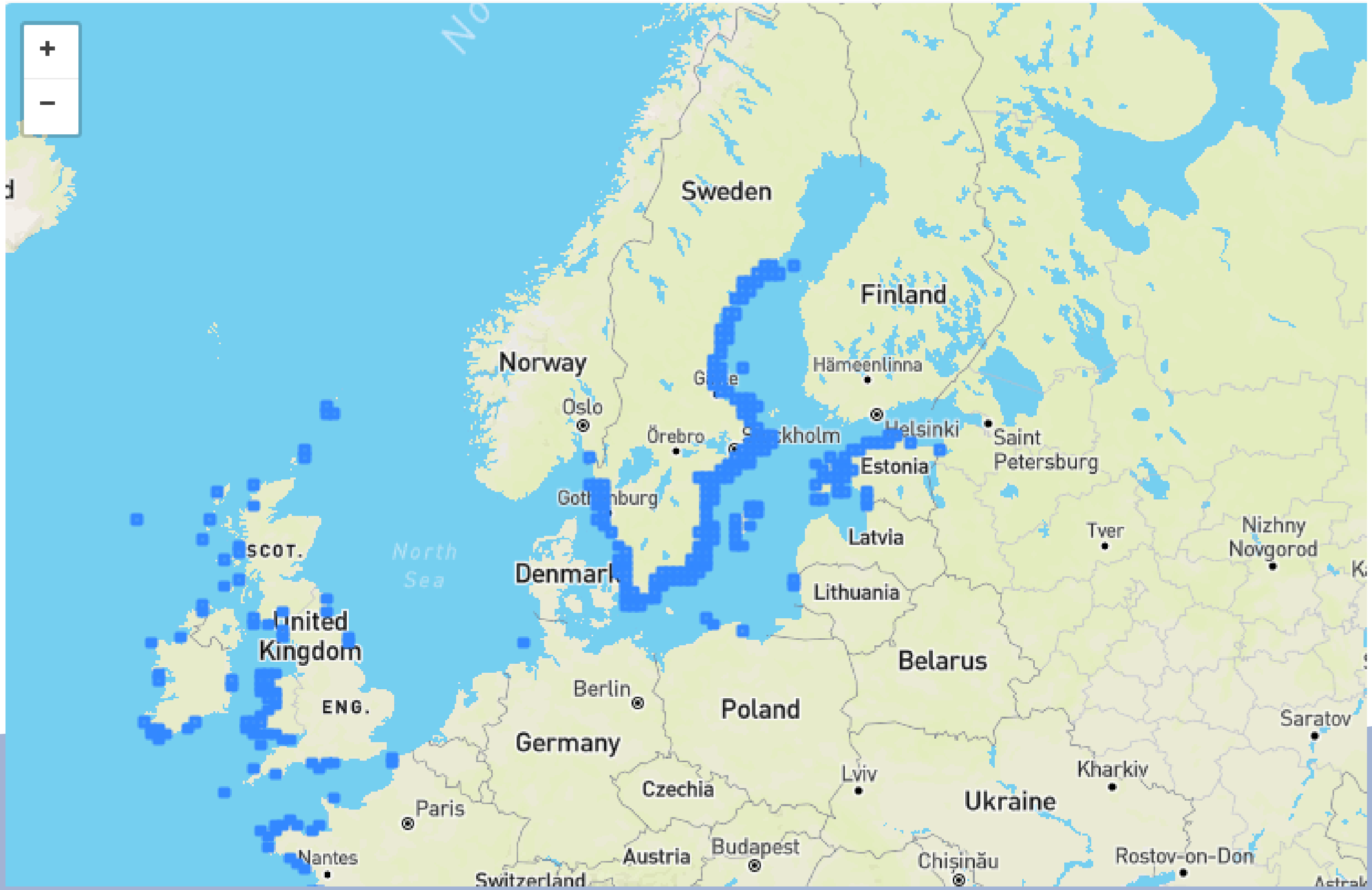
- Projects: FUCOSAN (https://www.interreg5a.eu/blog/projekt/fucosan/)

FUCOSAN Interreg Deutschland - Danmark EUROPEAN UNION

Baltic red algae

Furcellaria lumbricalis

Salinity preferences:
low (<18 psu), reduced (18-30 psu), variable (18-40 psu) / <u>down to 3 psu</u>
Site preferences:
macroalgae, bedrock, cobbles, large to very large boulders, pebbles, small boulders/ <u>free-floating forms</u>



https://www.marlin.ac.uk/species/detail/1616

Baltic red algae

Furcellaria lumbricalis

- nowadays unattached *F. lumbricalis* **only** in the area of the West Estonian Archipelago Sea (total bomass 179,000 t ww in 2017)
- new records in Poland in the Puck Lagoon

Weiberger et al. 2019

Baltic red algae

Furcellaria lumbricalis

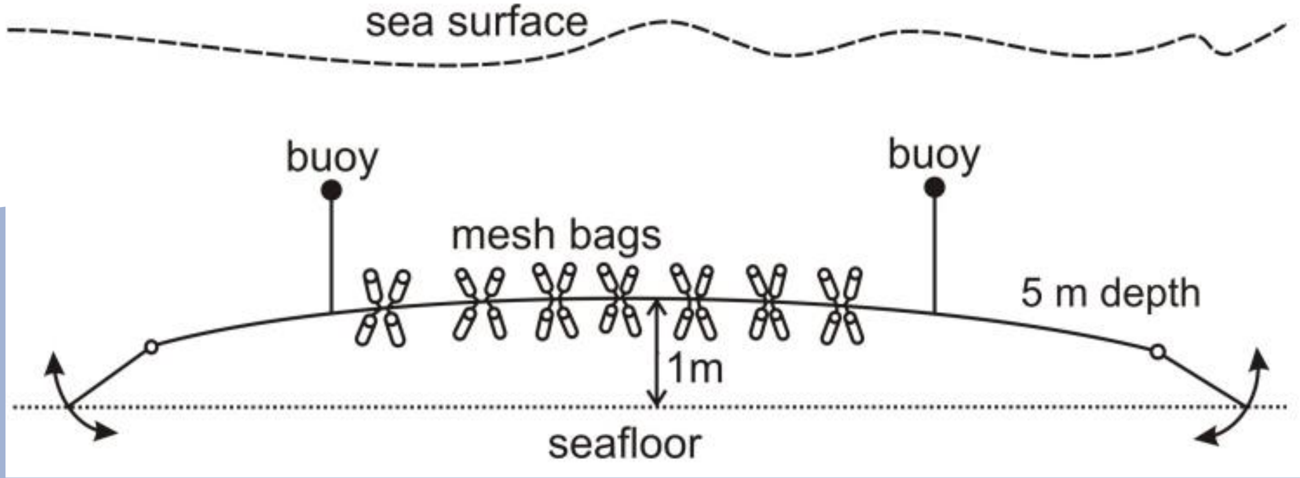
- exploited by ESTAGAR (from 1960) and VETIK (harvesting limited to 2,000 t /year)
- coast collection (ESTAGAR 100 – 1800T, plan for 2019 ~1200T

Photo: K. Lehis

Baltic red algae

Furcellaria lumbricalis

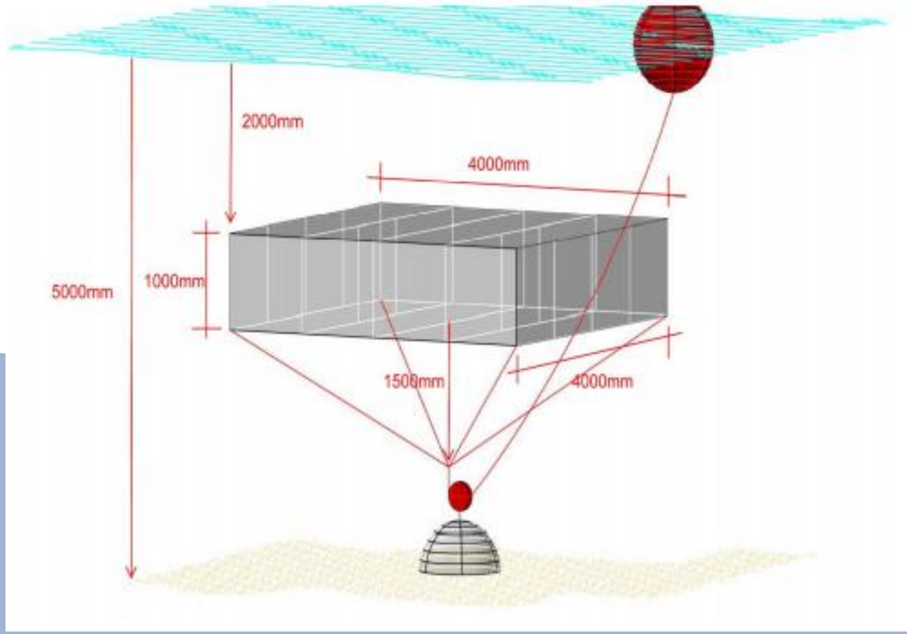
- cultivation experiment by Kotta et al. 2008 (growth **decreased significantly with increasing density** – are capable of regaining natural biomass under strong harvesting pressure, **growth controlled by light** not nutrients)



Baltic red algae

Furcellaria lumbricalis

- pilot project of cultivation by ESTAGAR



Baltic red algae

Palmaria palmata
Dulse

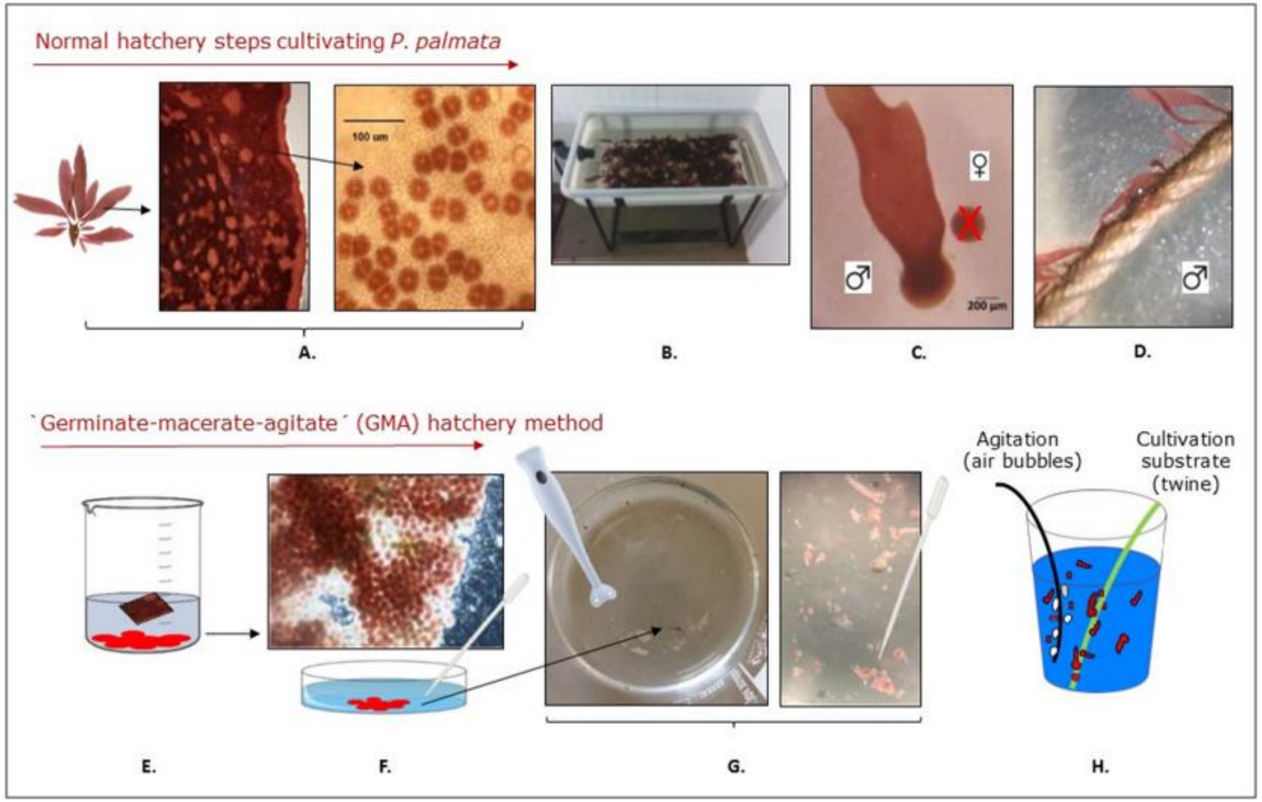
Salinity preferences:
full (30-40 psu)
Site preferences:
macroalgae, bedrock, large to very large boulders

https://www.marlin.ac.uk/species/detail/1405

Baltic red algae

Palmaria palmata

- well described the hatchery process

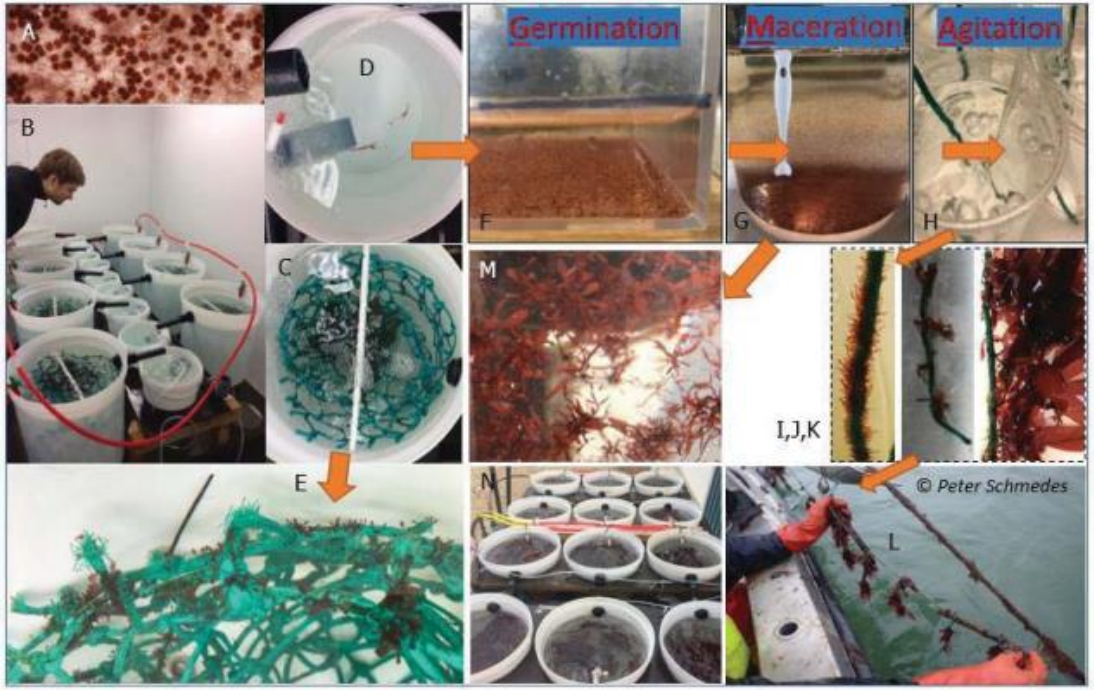


Schmedes et al. 2019, 2020

Baltic red algae

Palmaria palmata

- cultivation: Denmark < 1 t yr^{-1},
- wild harvest: Denmark < 1 t yr^{-1}, Norway



Grote 2017, Schmedes et al. 2019, 2020, Araujo et al. 2021

Macroalgae in the Baltic – future

- the **suboptimal geographic conditions** constitute an important limitation to the production of seaweeds in the Baltic Sea
- **algae exploitation** (harvesting and cultivation) **possible** but with lessons from the past in mind and further research

Thank you!

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Webpages used

https://www.seaweed.ie
https://www.submariner-network.eu
http://estagar.ee/
http://www.purealgae.dk/en/about-us/
http://www.seafarm.se/web/page.aspx?refid=198
https://www.leroyseafood.com
www.macrosea.no
https://www.sintef.no
https://balticseaweed.com – blog about Baltic macroalgae
https://www.interreg5a.eu/blog/projekt/fucosan/

Webpages used

https://www.submariner-network.eu/macro-algae-topic

Information hub on Macro-algae

Meet the Baltic Sea Macro-algae Community

- Royal Institute of Technology (KTH)
- Danish Technological Institute (DTI)
- Finnish Environment Institute (SYKE)
- Metal Production (LT)
- University of Tartu (Estonia)
- Blue Center Gotland
- Gothenburg University
- National Marine Fisheries Research Institute of Poland (NMFRI)
- Ocean Basis (DE)
- Coastal Research and Management (DE)
- Vetik (ET)
- KosterAlg (SE)
- Berrichi (Furcella) (ET)
- Organic Seaweed (DK)
- BIOFISK (DK)
- Department of Seaweed (DE/UK)
- University Medical Center Schleswig-Holstein (DE)
- Movable Biogas Factory
- Uni Gdansk Bloom
- Zostera (DK)
- FermantationExperts (DK)
- Origin by Ocean (FI)
- Lerøy (NO)
- Havhøst - Maritim Nyttehaver (DK)

Projects

- Algae2Future
- ALGET2
- ALGINIANS
- Baltic Blue Biotechnology Alliance
- BaMS
- BIOCAS
- Blue Adapt (FI)
- Coastal Biogas
- CONTRA
- EnAlgae
- GRASS
- FUCOSAN
- Havhøst- Maritim Nyttehaver (DK)
- MAB4
- Macrocascade
- MacroFuels
- NetAlgae
- POSIMA
- Seafarm
- Seafeed
- Seagas
- SW-GROW
- TANG.NU
- UNITED

Publications

Various:

Weinberger, Florian, Paalme, Tiina and Wikström, Sofia A.. "Seaweed resources of the Baltic Sea, Kattegat and German and Danish North Sea coasts" *Botanica Marina*, vol. 63, no. 1, 2020, pp. 61-72. https://doi.org/10.1515/bot-2019-0019

Kotta J., Jänes H., Paalme T., Peterson A., Kotta I., Aps R., Szava-Kovats R., Kaasik A., Fetissov M., 2020 GoA 2.1. Assessing the PanBaltic potential of macroalgae cultivation and of harvesting wild stocks, https://www.submariner-network.eu/grass

Daniel Franzén, Hanna Nathaniel, Sofia Lingegård and Fredrik Gröndahl, 2020 Macroalgae Production Manual Production, Challenges & Pathways

Ulva spp.:

Nielsen, Mette & Bruhn, Annette & Rasmussen, Michael & Olesen, Birgit & Larsen, Martin & Møller, Henrik. (2011). Cultivation of Ulva lactuca with manure for simultaneous bioremediation and biomass production. Journal of Applied Phycology. 24. 10.1007/s10811-011-9767-z.

Sode, Sidsel & Bruhn, Annette & Balsby, Thorsten & Larsen, Martin & Gotfredsen, Annemarie & Rasmussen, Michael. (2013). Bioremediation of reject water from anaerobically digested waste water sludge with macroalgae (Ulva lactuca, Chlorophyta). Bioresource technology. 146C. 426-435. 10.1016/j.biortech.2013.06.062.

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Palmaria palmata:

Grote B. 2017. Recent developments in aquaculture of Palmaria palmata (Linnaeus) (Weber & Mohr 1805): cultivation and uses. Reviews in Aquaculture (2017) 0, 1–17. doi: 10.1111/raq.12224

Schmedes, Peter & Nielsen, Mette. (2020). New hatchery methods for efficient spore use and seedling production of Palmaria palmata (dulse). Journal of Applied Phycology. 32. 10.1007/s10811-019-01998-0.

Schmedes, Peter & Nielsen, Mette & Petersen, Jens. (2019). Improved Palmaria palmata hatchery methods for tetraspore release, even settlement and high seedling survival using strong water agitation and macerated propagules. Algal Research. 40. 101494. 10.1016/j.algal.2019.101494.

Fucus spp.:

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Møller Nielsen M., Manns D., D'Este M., Krause-Jensen D., Rasmussen M.B., Larsen M.M., Alvarado-Morales M., Angelidaki I., Bruhn A., 2016. Variation in biochemical composition of Saccharina latissima and Laminaria digitata along an estuarine salinity gradient in inner Danish waters, Algal Research, Volume 13, Pages 235-245, ISSN 2211-9264, https://doi.org/10.1016/j.algal.2015.12.003.

Visch W. 2019. PhD thesis, Sustainable Kelp Aquaculture in Sweden, University of Gothenburg

Forbord, Silje & Steinhovden, Kristine & Solvang, Torfinn & Handå, Aleksander & Skjermo, Jorunn. (2020). Effect of seeding methods and hatchery periods on sea cultivation of Saccharina latissima (Phaeophyceae): a Norwegian case study. Journal of Applied Phycology. 32. 1-12. 10.1007/s10811-019-01936-0.

Boderskov T., Nielsen M.M., Rasmussen M.B., Skovbjerg Balsby T.J., Macleod A., Løvstad Holdt S., Sloth J.J., Bruhn A. 2021. Effects of seeding method, timing and site selection on the production and quality of sugar kelp, Saccharina latissima: A Danish case study, Algal Research, Volume 53, 102160, ISSN 2211-9264,https://doi.org/10.1016/j.algal.2020.102160.

Boderskov, T., Rasmussen, M.B. & Bruhn, A. Obtaining spores for the production of *Saccharina latissima*: seasonal limitations in nature, and induction of sporogenesis in darkness. *J Appl Phycol* 33, 1035–1046 (2021).

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Kersen, P. Martin, G. 2007. Annual biomass loss of the loose-lying red algal community via macroalgal beach casts in the Väinameri area, NE Baltic Sea. Proceedings of the Estonian Academy of Sciences. Biology, Ecology, 56(4), 278–289.

Kotta, J., Paalme, T., Kersen, P., Martin, G., Herkül, K. & Möller, T. 2008. Density dependent growth of the red algae Furcellaria lumbricalis and Coccotylus truncatus in the West Estonian Archipelago Sea, northern Baltic Sea. Oceanologia, 50(4), 577–585.

Kersen, P., Orav-Kotta, H., Kotta, J. & Kukk, H. 2009. Effect of abiotic environment on the distribution of attached and drifting red alga Furcellaria lumbricalis in the Estonian coastal sea. Estonian Journal of Ecology, 58(4), 245–258.

Paalme, T., Kotta,J., Kersen, P., Martin, G., Kukk, H. & Torn, K. 2011. Inter-annual variations in biomass of loose lying algae Furcellaria-Coccotylus community: the relative importance of local versus regional environmental factors in the West Estonian Archipelago. Aquatic Botany, 95(2), 146–152.

Paalme, T., Kotta, J. & Kersen, P. 2013. Does the growth rate of drifting Furcellaria lumbricalis and Coccotylus truncatus depend on their proportion and density? Proceedings of the Estonian Academy of Sciences, 62(2), 141–147.