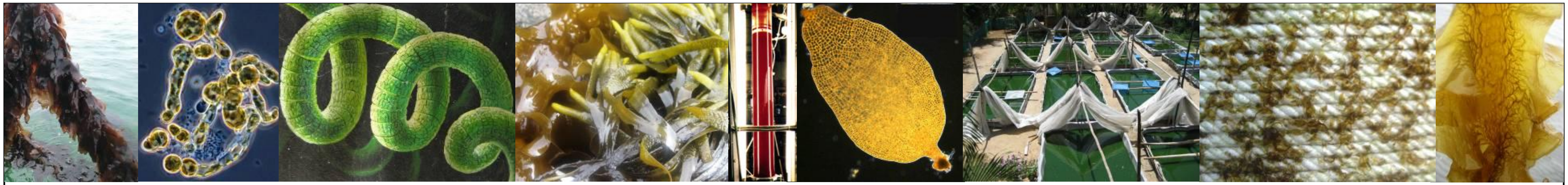
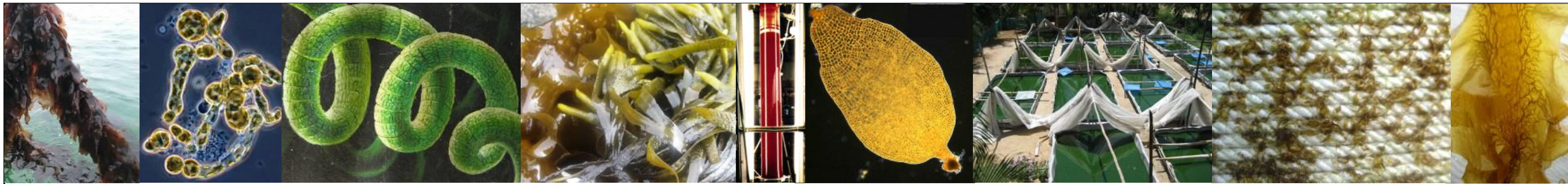


# Algal cultivation: a ”new” resource for biorefineries

Susan Løvstad Holdt

Researcher at Biological Institute, KU and DTU Environment

DTU



# Objectives

- Biorefinery **biomass**
- Harvest vs. Cultivation
- Cultivation methods:
    - Closed photobioreactors
    - Open pond
    - Field
- Examples of yields
- Micro vs. Macroalgae

Choice of algae

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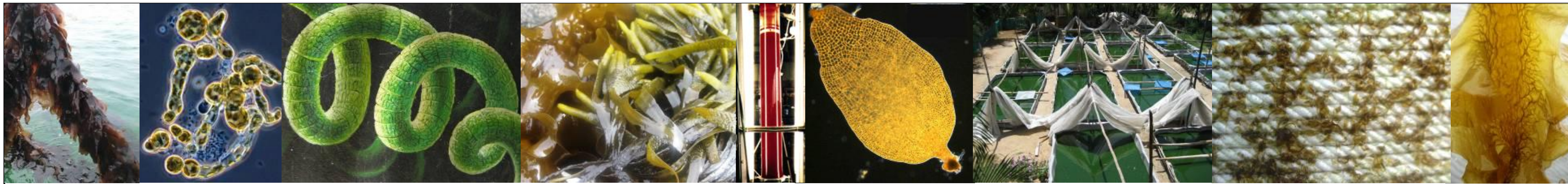
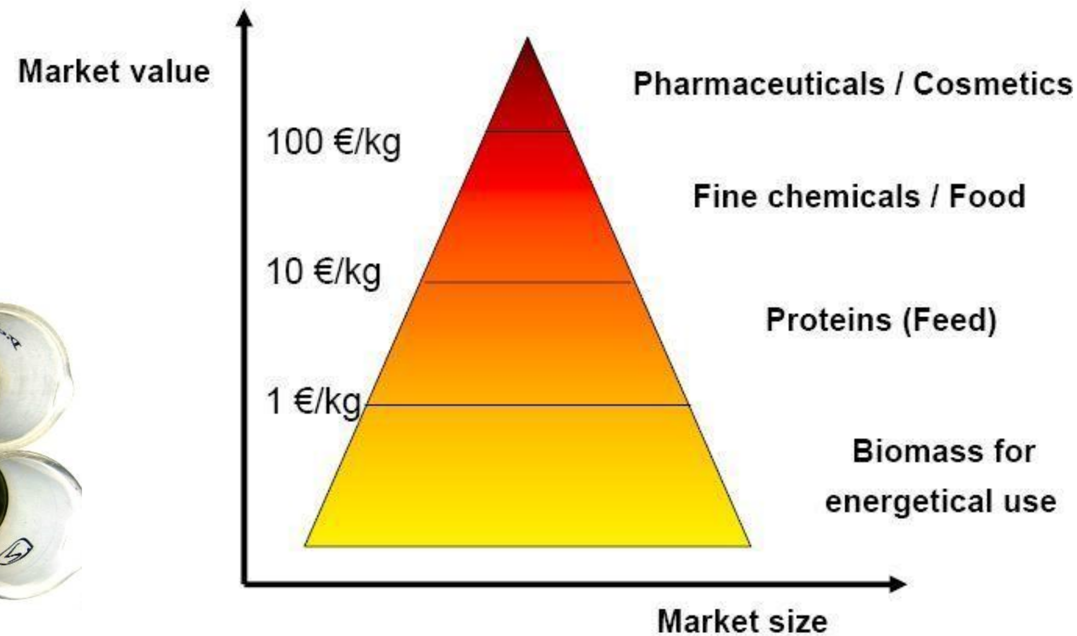


# Criteria for species selection in DK

-High in added value products
-High growth rate
-Low cultivation costs/manpower




-Soil enrichment and energy potential are low in priority, however possible in the waste of all species

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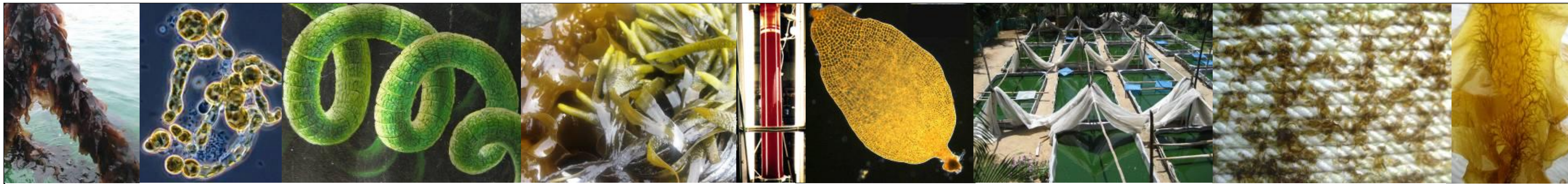
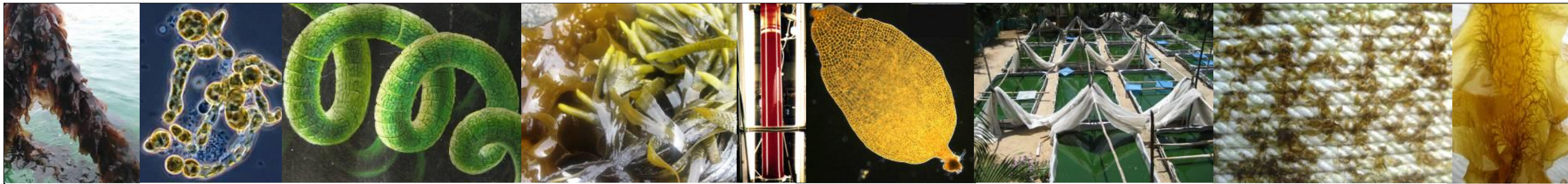
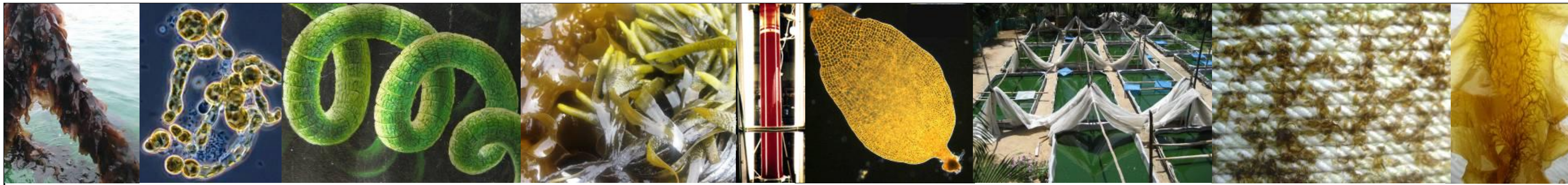


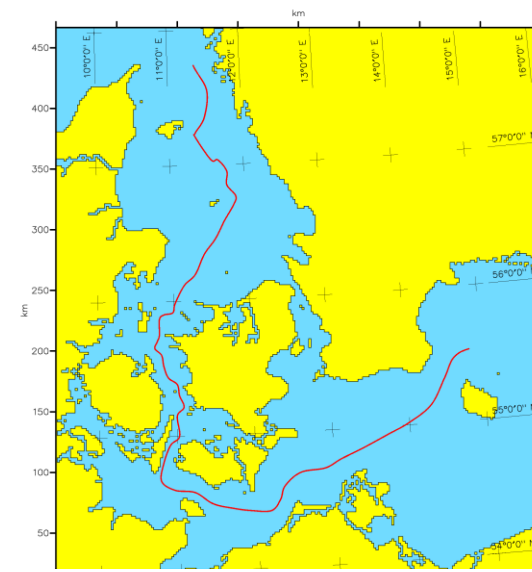
# Biomass…….Harvest or cultivation

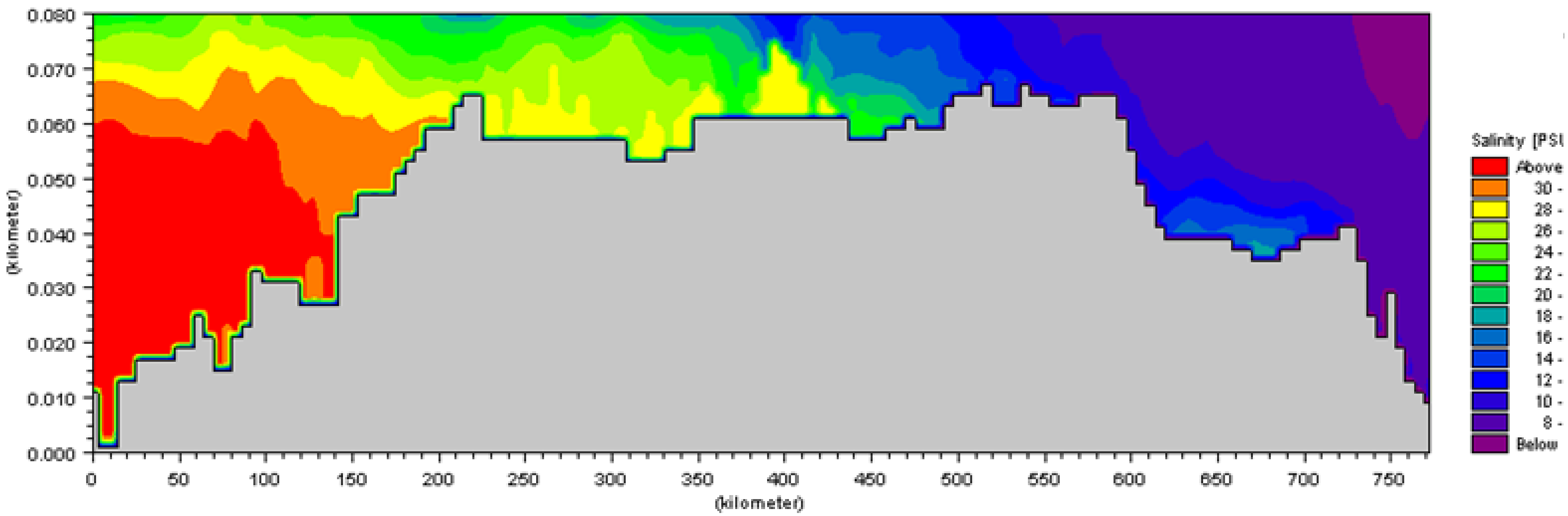




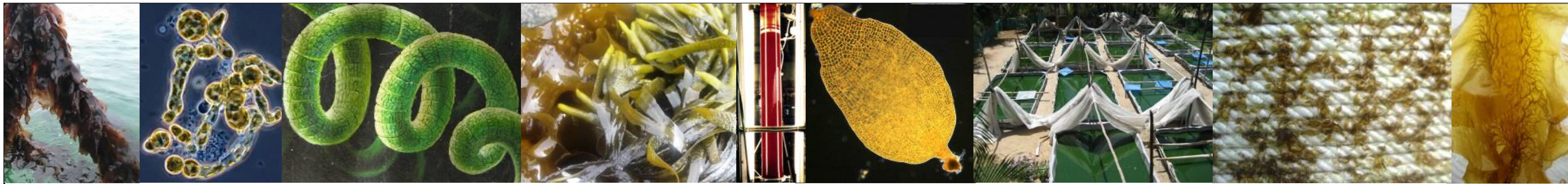
# Substrate and salinity

- Number of species
- Specimen size






DHI- The water Forecast



## Requirements

Water

(fresh or seawater)

Light

$CO_2$

Nutrients

Mixing/water movemen

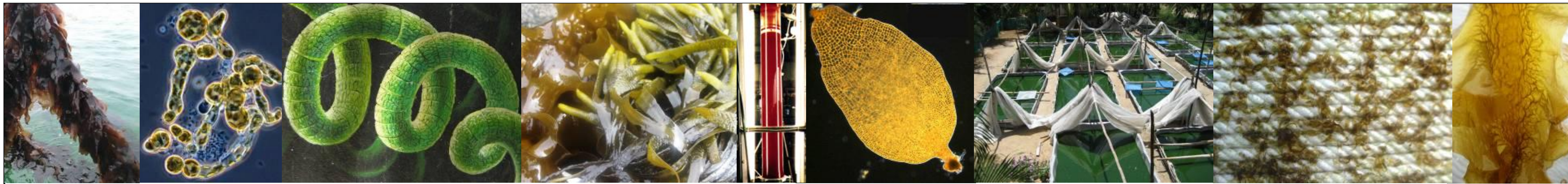
→

→

## End product

$O_2$

Biomass

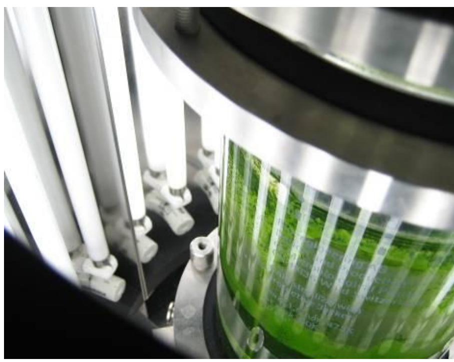


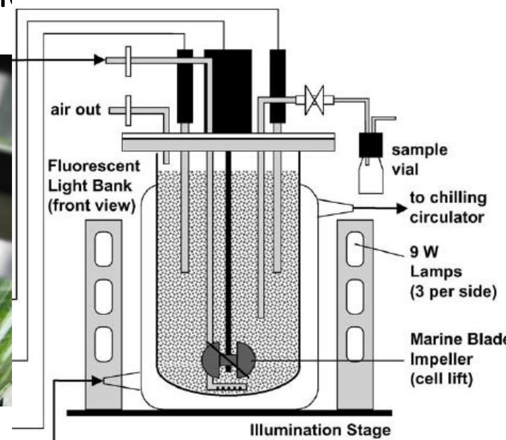
# Cultivation methods:

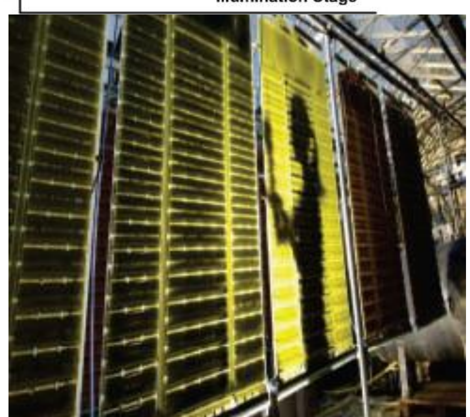
## Biomass growth: microalgae or thallus

### Closed photobioreactors

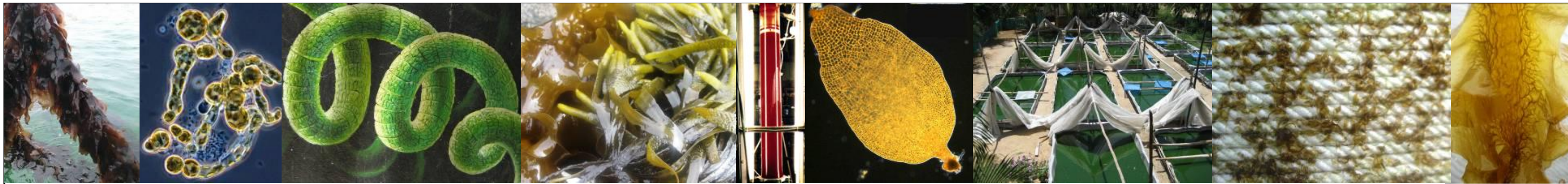
AquaCare





Flat Panel Airlift Reactor in Stuttgart, Germany *(Subitec)*

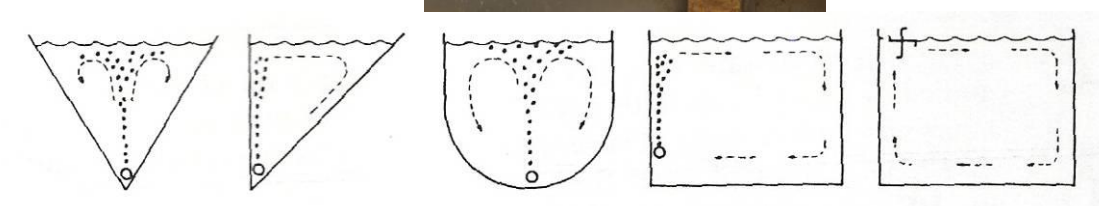


# Cultivation methods:

## Biomass growth: microalgae or thallus

### Open pond systems

Open-pond Test Facility at Ashkelon *(Seambiotic)*



Cross section of different kinds of tanks used to cultivate seaweeds. The circulation of the algae is given by air bubbling, or by paddlewheels as depicted in the sketch at the right (Oliveira and Alveal 1990).

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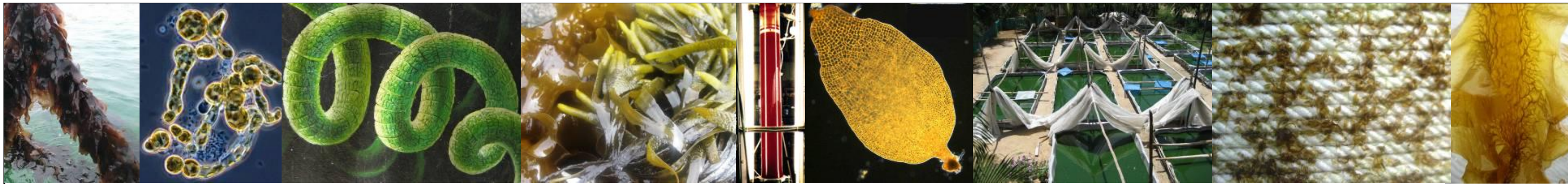
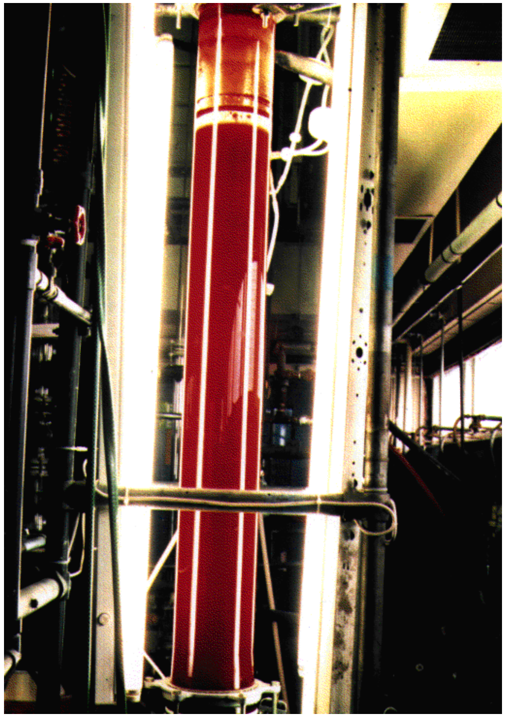
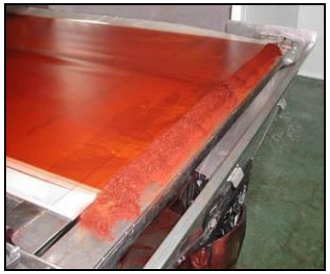


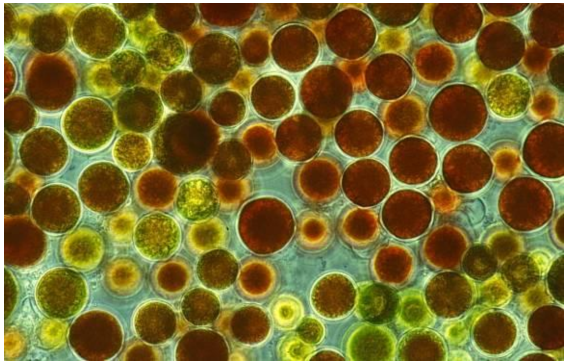
# Pigments from algae

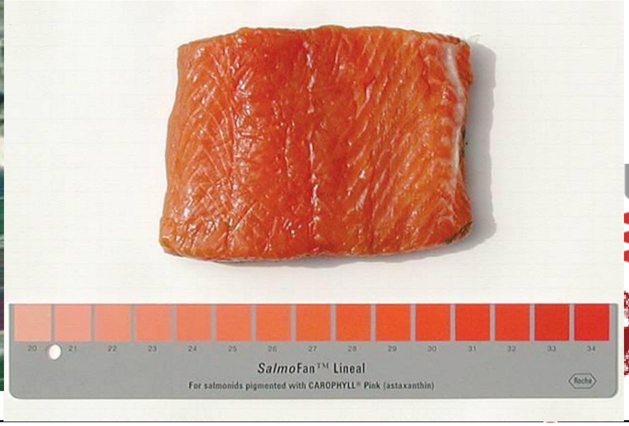
## Astaxanthin – 8000 US$/kg



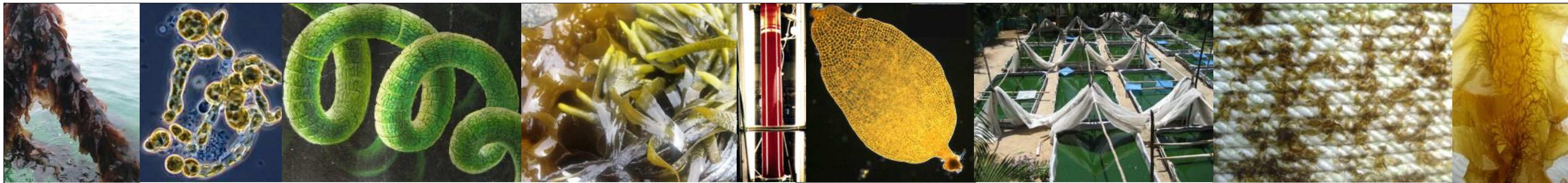


*Haematococcus* sp.





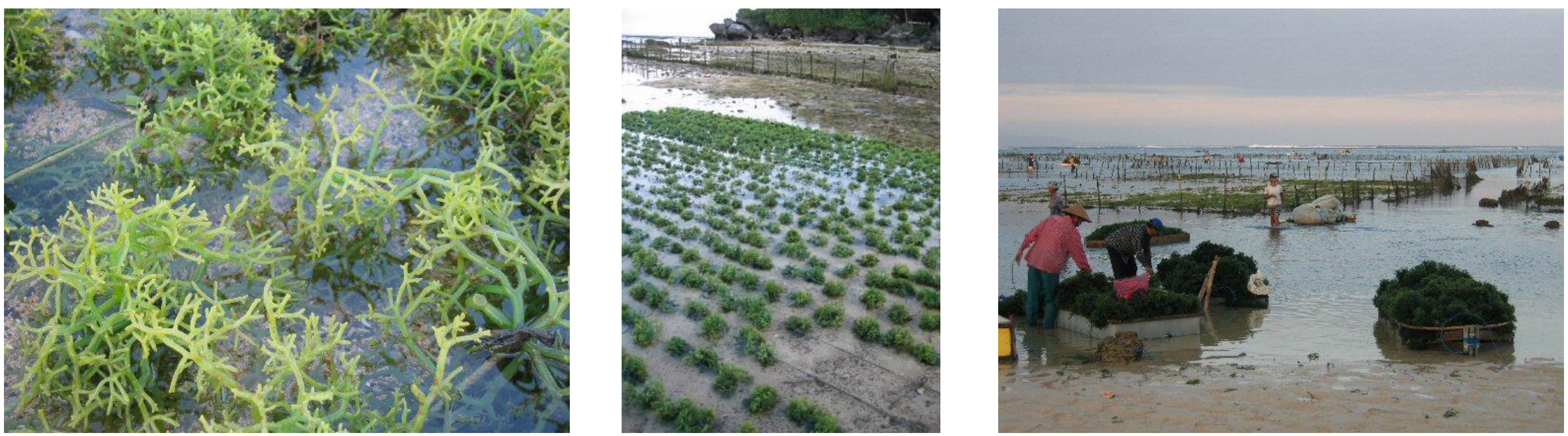

http://www.themagicisbac.com/bac-files/haematococcus.jpg
http://algae4oil.com/_borders/clip_image001_000.jpg
http://www.edwardtufte.com/bboard/images/0000c7-699.jpg



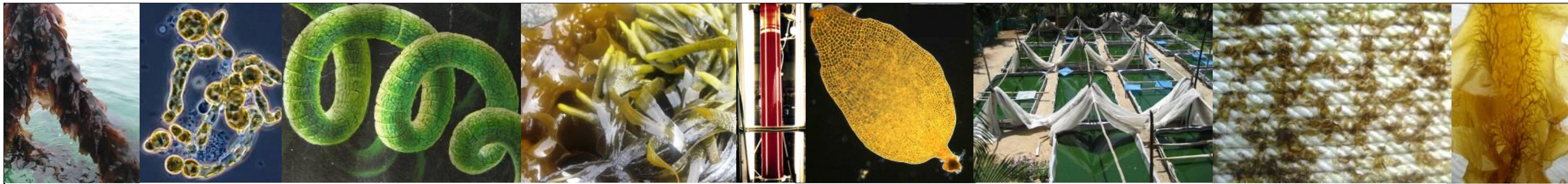
# Cultivation methods:

## Biomass growth: thallus/seaweed

### Field cultivation



Seaweed production in Indonesia:*Kappaphycus alverezii* produced to utilize carrageenan. left: Close-up of *K. Alverezii* tied onto ropes. Right centre: Seaweed on ropes at low tide. Right: The seaweed farmers harvest seaweed from the ropes at low tide.

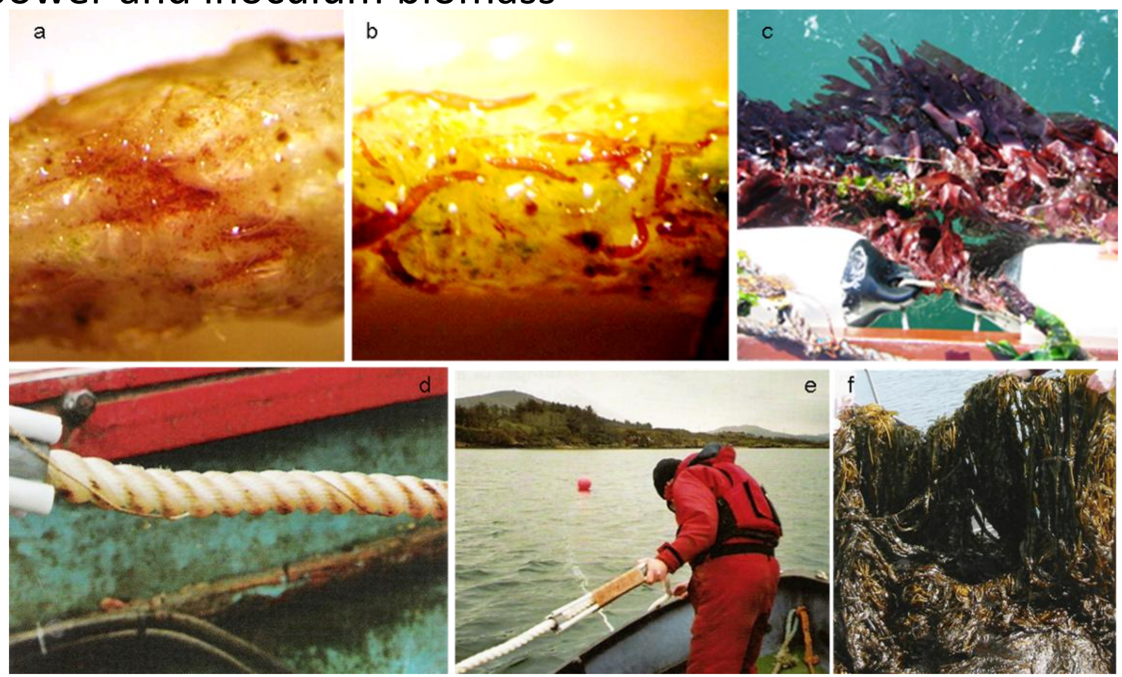


# Cultivation methods:

## Biomass growth: Thallus->Spores->germination

Field cultivation or the other methods

Less man power and inoculum biomass




(a) Spores from *Palmaria palmata* settled on vinylon string (2 mm in diam), (b) spores germinated in 3 weeks in nursery tanks with added nutrient and aeration and transferred to the field at this stage, (c) harvestable thalli after 4 months of field cultivation (a-c seeded and cultivated by Maeve Edwards). (d-e) Seeded string with *Alaria esculenta* coiled around culture rope and (f) *Alaria* afer approximately 120 days culture at sea (Arbona and Molla 2006).

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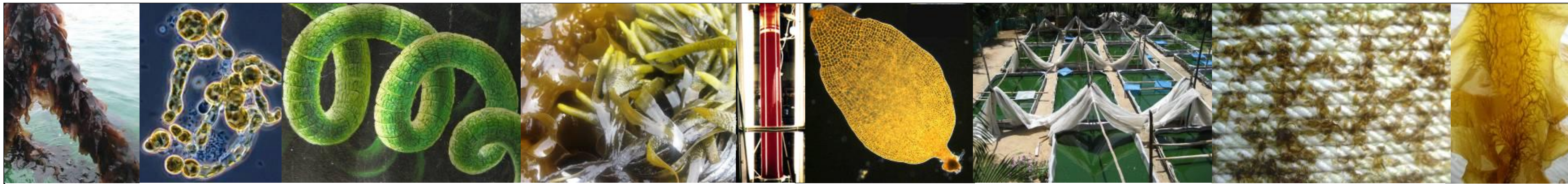
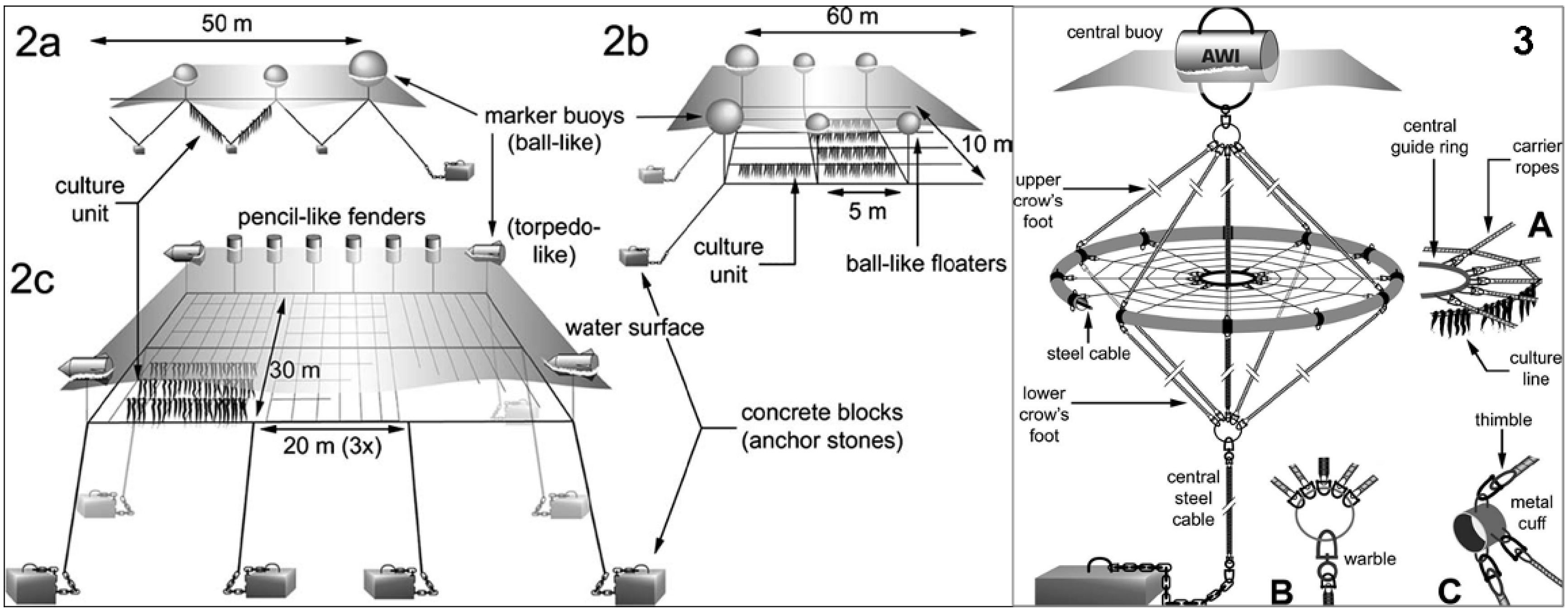


# Cultivation design




(2) System designs for *Laminaria* culture tested within the area of Helgoland farm. (A) Longline construction with perpendicular culture unit. (B) Ladder construction, with culture lines knotted between the "steps". (C) Grid design with rectangular culture units.
(3) The successful patended ring design for the culture of *Laminaria* at offshore locations. The major elements of the system design are magnified: (A) central guide ring with attached carrier rope and culture line, (B) the transition between central steel cable of the mooring and that of the lower crow's foot, (C) metal cuffs, to which the crow's feet and the carrier ropes are attached (Buck and Buchholz 2004; Buck and Buchholz 2005).

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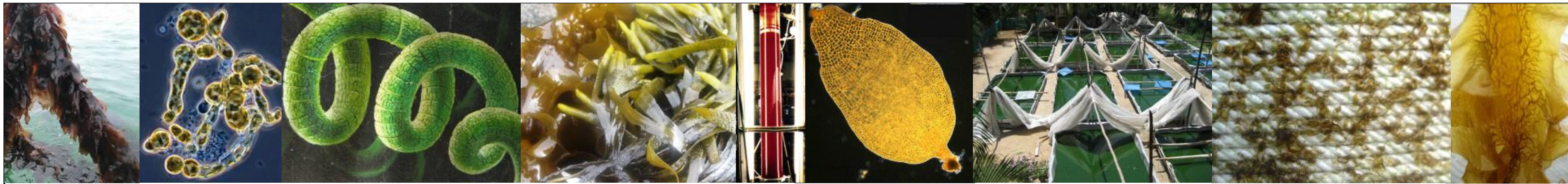


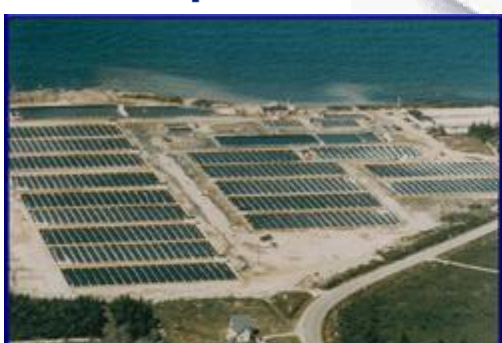
# Cultivation methods:

## Biomass growth: Cell, callus or protoplast method

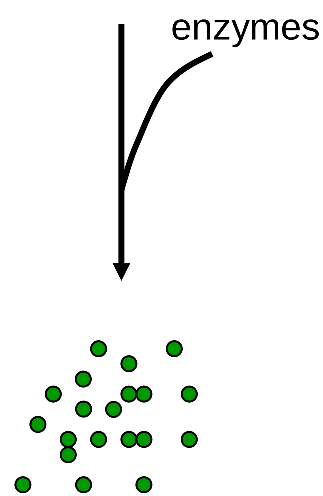
These methods are often used in order to retrieve morphological and genetically similar cultures of macroalgae or to reduce contaminants.

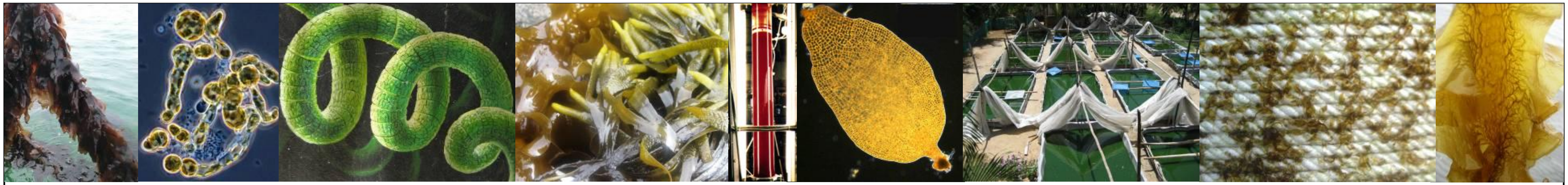
Single cells

Acadian Seaplants



protoplast





# Cultivation methods:

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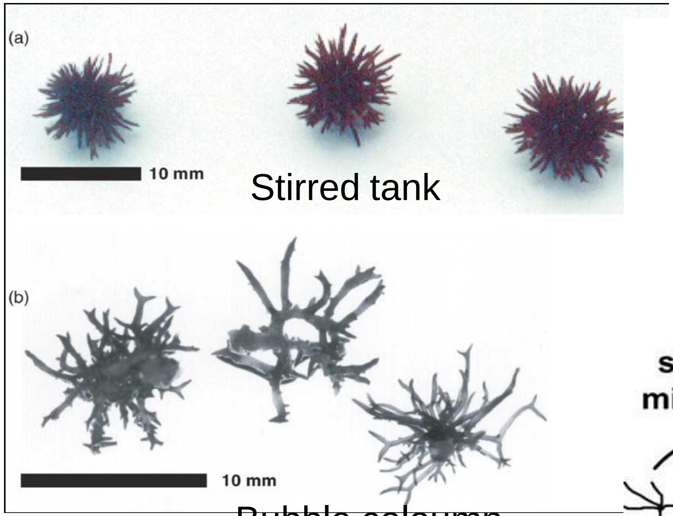
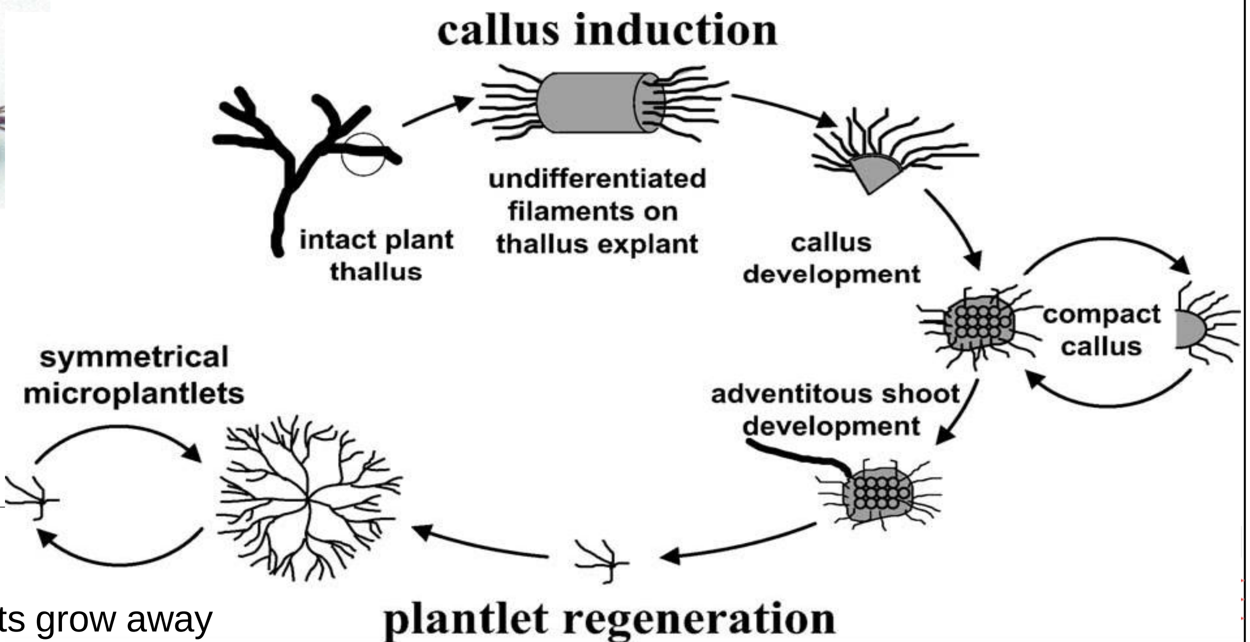
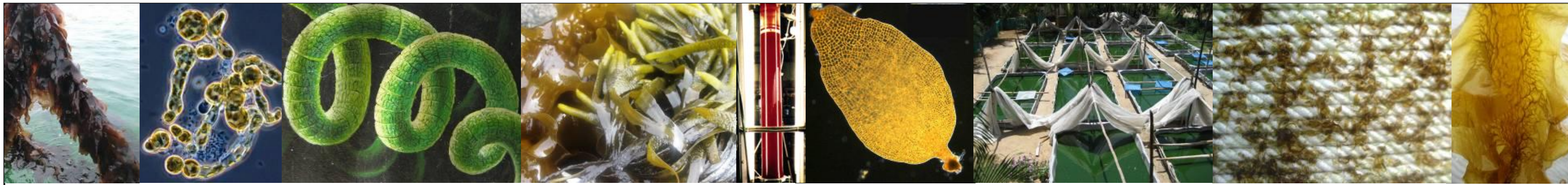



Stirred tank

Bubble coloumn




Callus: undifferentiated cell filaments grow away from the cut face of a thallus explant and these shoot tissues are regenerated into microplantlets (Rorrer and Cheney, 2004)



# Yield of microalgae?

# Example of area demand for oil production

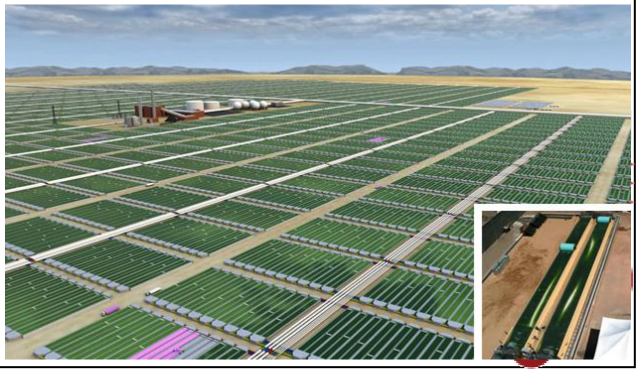
Production of microalgae on about 30 $g/m^2/d$
40 % lipid- or oil content
$\Rightarrow$12 g lipids/$m^2$/d

$\Rightarrow$ to produce 1 liter lipid/day a 83 $m^2$ tank is needed

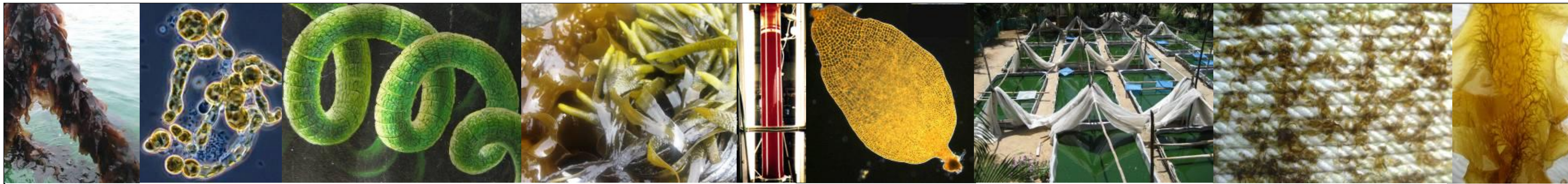
The oil demand is:

Australia: 796,500 barrels oil/d
North America: $19{,}6 \cdot 10^6$ barrels oil/day

To produce 1 % of Australias daily need will need an area of 10.500 ha….. ***land***



Future at Solix, http://jellyfishcoolman.files.wordpress.com/2009/09/solix_bioreactor2.jpg

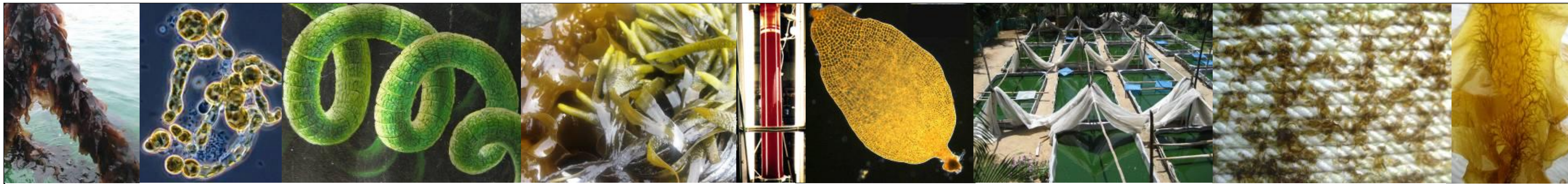


# Seaweed yield

**Table 8: Selected Macroalgae Cultivation Productivity**

| Species | Yield t/ha/yr dry | Location | Origin | Source | Notes |
|---|---|---|---|---|---|
| *L japonica* | 31 | Japan | Cultivation | Yokoyama et al, citing Japan Ocean Industries Association | Corrected from dry ash-free value |
| *L japonica* | 25 | China | Cultivation | Kelly, citing China Fish Annals 2003 | Commercially achieved yields |
| *L japonica* | 60 | China | Cultivation | Kelly, citing Tseng 1987 | Experimental plots. High cost and poor quality |
| *Alaria* | 12 | Ireland | Cultivation | Kelly, citing Kraan 2007 | Hybrid species |
| *Saccharina latissima* | 15 | Scotland | Cultivation | Kelly, citing Sanderson 2006 unpublished | Experimental plots near fish farms as nutrient source |
| *S polyschides* | 25.5 | Scotland | Cultivation | Kelly, citing Sanderson 2006 unpublished | Experimental plots near fish farms as nutrient source |
| *Ulva* | 22.5 | Pennsylvania | Cultivation | Rasmussen 2007, citing Moll 1998 | Converted to annual yields using 6 months growth |
| *Ulva* | 45 | Denmark | Cultivation | Rasmussen pers. Comm. 2008 | Based on extrapolation of 4-month trials |

Sustainable Energy Ireland, 2009



# Visual pollution

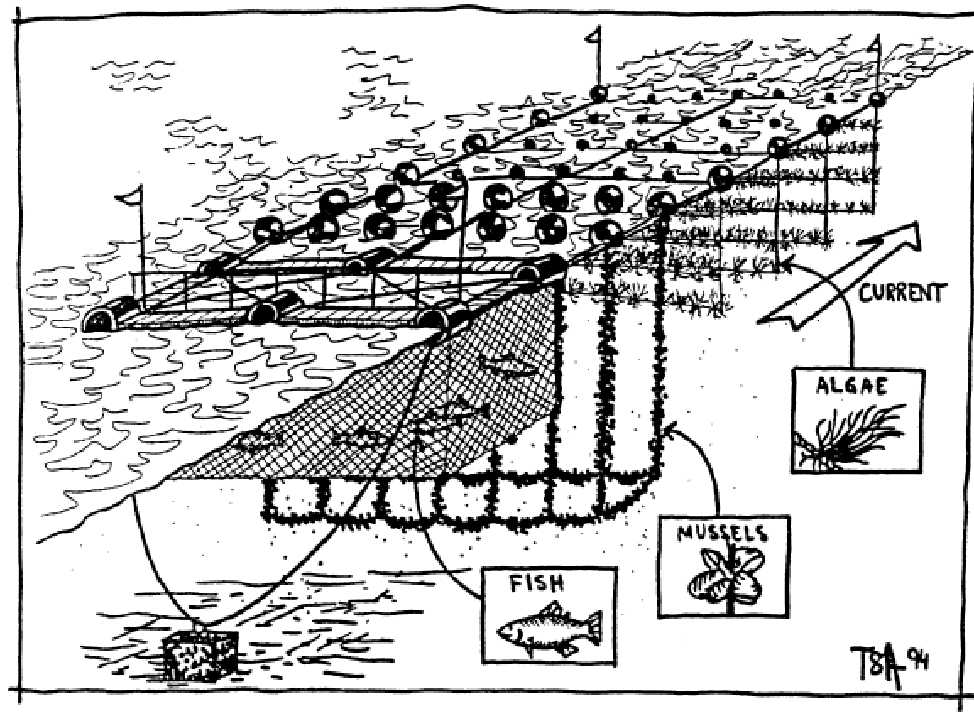
Annual yield per hectare

| | kg vådvægt | kg tørvægt |
|---|---|---|
| **2. år- 25 liner a 200 m** | | |
| Tangproduktion | 120.000 | 17.143 |
| N-reduktion | | 394 |
| P-reduktion | | 51 |
| $CO_2$-reduktion | | 14.000 |

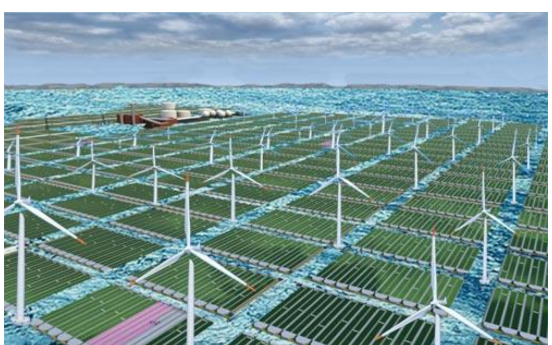
Reduce N-waste of fish farms with 10 %:

Musholm Lax: 3,000 t fish: 25 ha

Agersø Havbrug: 260 t fish: 3 ha seaweed




Schematic of integrated multitrophic aquaculture (IMTA) with fish, mussels and macroalgae (seaweed) to reduce nutrient wastes from intensive aquaculture operations (reference in Troell and Norberg 1998).



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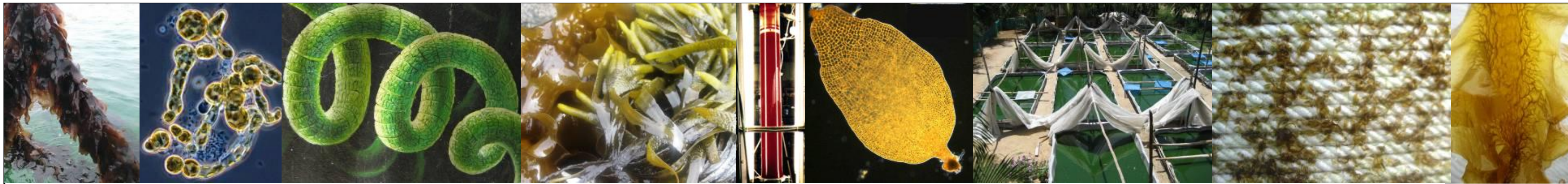
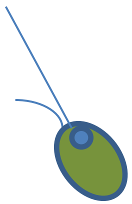
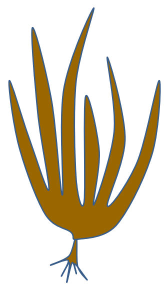


# Macro and microalgal cultivation

**Landbased (tanks) and bioreactors**

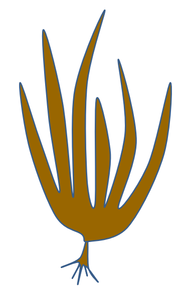
- Controlled
  - light
  - nutrients
  - flow
  - fouling
- Safe
- Harvest!
- Expensive (energy, nutrients)
- Maintenance (man power)

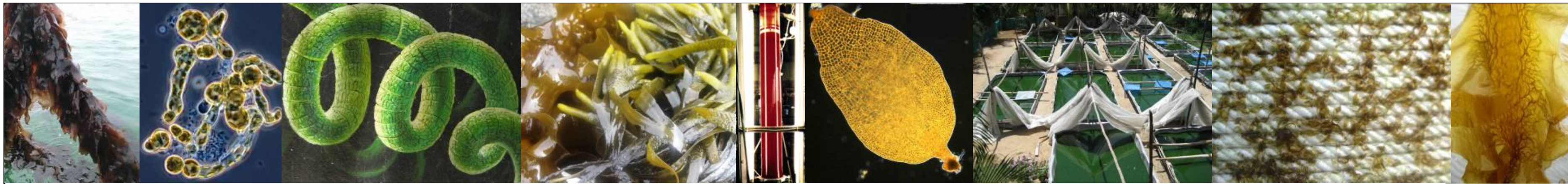




**Off-shore (lines/floating)**

- No control on growth parameters
- Higher risk
- Cheaper
- No use of agricultural land
- Visual pollution





# Choice of algae species depends on products

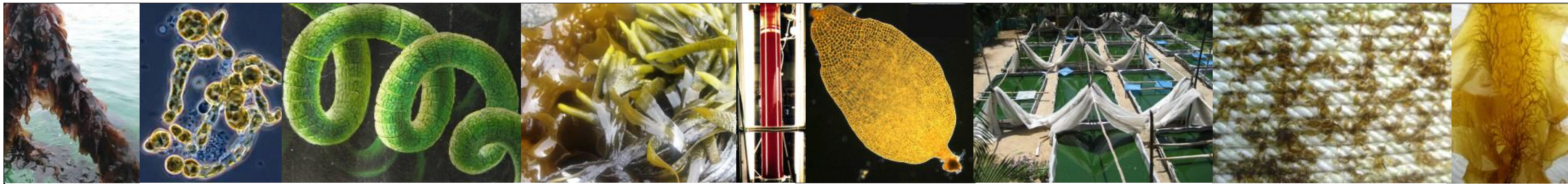
| | Micro | Macro |
|---|---|---|
| Polysaccharides | Low (4-60 %) | **High** (15 to 75 %) |
| Lipids | **High** (up to 40 %) | Low (max 4 %) |
| Proteins | Similar (6-60 %) | Similar (5-50 %) |
| Pigments | Similar/but different types | Similar/but different types |
| Phenolics (flavonoids) | Similar (up to 16 %) | Similar (up to 14 % in brown sp.) |

fish feed (omega-3 and protein)

Pigments

alginate

Phenolics/flavonoids/phlorotannins

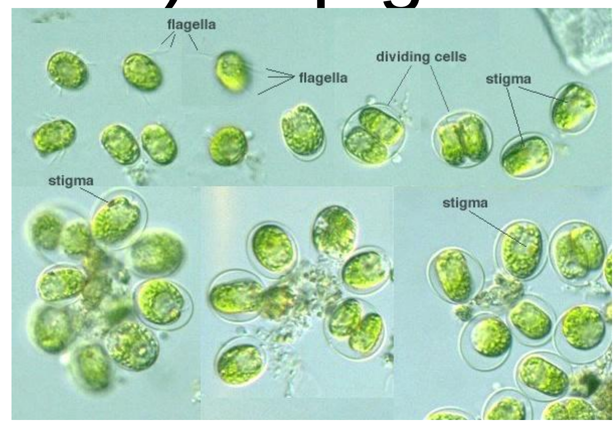


# Omega 3/ PUFA (EPA, DHA) or pigments

## Aquaculture feed

*Tetraselmis striata*
*Tetraselmis chui*
Total lipids of 9-22 % of dw

*Nanochloropsis oculata*
Total lipids of 18-32 % of dw

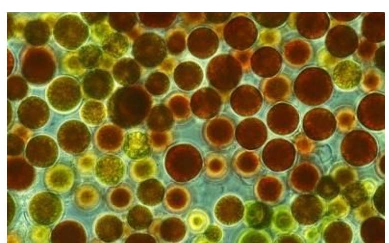


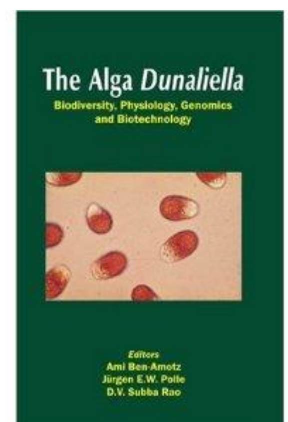

http://protist.i.hosei.ac.jp/pdb/images/Chlorophyta/Tetraselmis/index.html
www.algaedepot.com

*Dunaliella* sp.

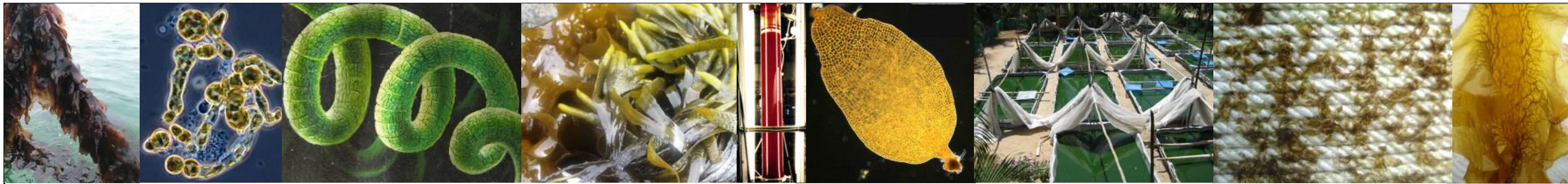
*Haematococcus* sp.
Astaxanthin

http://cid-12da36d60f963106.spaces.live.com/blog/






www.dunaliella.org



# Macroalgae

*Saccharina latissima*

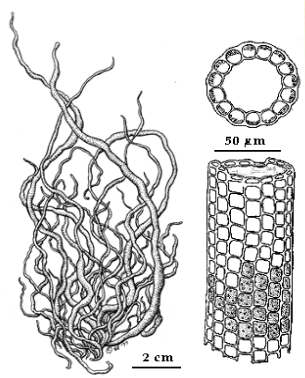
polyphenols (antioxidants)
Laminaran
Mannitol
Pigments

*Laminaria digitata*

polyphenols (antioxidants)
Laminaran
Mannitol
Pigments

*Ulva* sp.
*Enteromorpha* sp.

High growth rate (>0.15/d)
ulvan




http://ucjeps.berkeley.edu/guide/green31.html

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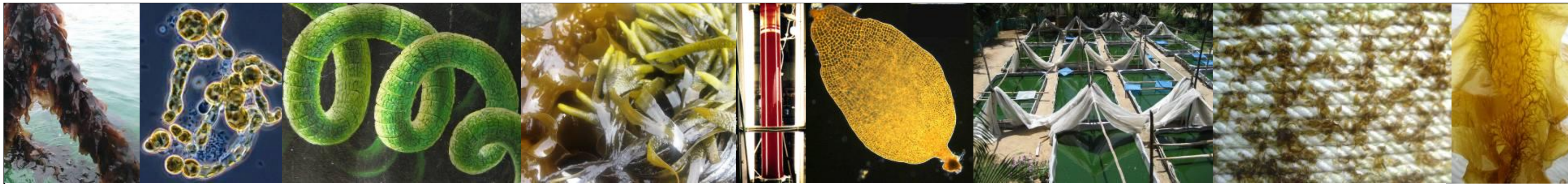
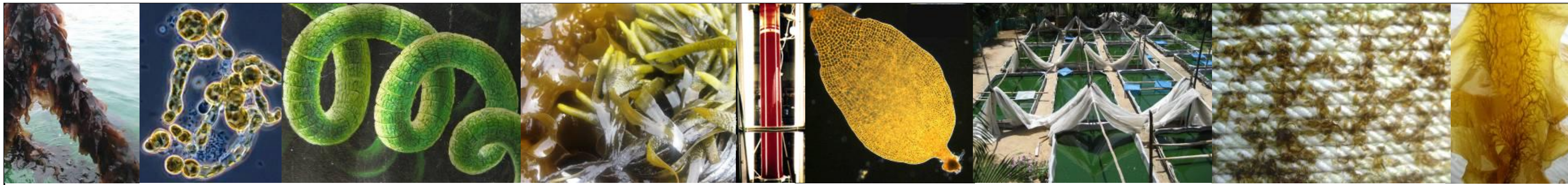


Holdt SL and Kraan S (2010)
Bioactive compounds in seaweed; functional food applications and legislation
(DOI: 10.1007/s10811-010-9632-5 )

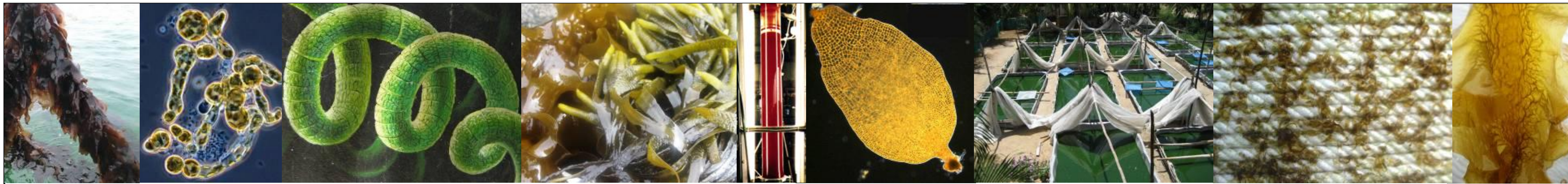

Table 5. Polysaccharides in seaweed species with characteristics, source and bioactivity

| | Characteristics | Source and content | Bioactivity |
|---|---|---|---|
| Polysaccharides | Total | *Saccharina latissima* [a]<br>*Sargassum pallidum* [b,c] | Antitumor action [a, b]<br>Potent anti-coagulant [c]<br>Decrease in LDL-cholesterol in rats [d]<br>Anti-herpetic [e] |
| Phycolloids | Algins/alginic acid | *Undari pinnatifida* [a]: 24 % [f]<br>*Laminaria digitata*: 32 % [g]<br>*Laminaria* sp. [i]<br>*Sargassum vulgare* [l]<br>*Ascophyllum nodosum*: 28 % [g] | Anticancer [a] |
| | Carrageenans | *Chondrus crispus* [h,i]<br>*Eucheuma cottonii* [m] | Antitumor and immunomodulation [j,k]<br>Anti-HIV [i], but no efficacy on humans [l] |
| | Agar | *Gracilaria* sp., Gigartina sp. etc. [m] | |
| Fucoidan<br>ranging from typical fucoidans (major components) to low sulphate-containing heteropolysaccharide-like fucans (minor components) [o] | Fucan<br>composed of neutral sugars other than fucose and a high content of uronic acid(s) [o] | *Sargassum horneri* [c]<br>*Sargassum vulgare*: uronic acid, xylose and fucose accounted for >90 % of total sugars [l]<br>*Fucus vesiculosis* [o]<br>*Undaria pinnatifida* [p] | Potential antiviral [c]<br>Slightly anticoagulant activity [o]<br>Anti-herpetic [p] |
| | Fucoidan=fucan sulphate, containing mainly L-fucose, sulphate, and no uronic acid [o,q] | *Laminaria digitata*: 5.5 % [g]<br>*Laminaria* sp. [i]<br>*Ascophyllum nodosum* [r]: 12 % [g]<br>*Undaria pinnatifida* [p,s,t]: 1.5 % [f]<br>*Fucus vesiculosis* [o]<br>*Eisenia bicyclis* [i] | Potential antiviral (HIV and HSV) [e,s,t,v]<br>Anticoagulant [o,x]<br>Anti-arteriosclerosis [a]<br>Anti-cancer [a,y]<br>Potential antiviral against human cytomegalovirus and avian flue [s]<br>Anti-tumor activity [i]<br>Inhibits growth of *Cryptosporidium parvum* in mice [z] |
| Mannitol | | *Laminaria digitata*: 13 % [g]<br>*Laminaria* sp. [i]<br>*Sargassum mangarevense*: 1-12 % [æ]<br>*Ascophyllum nodosum*: 7.5 % [g] | Effectively protects the photosynthetic apparatus from low-salinity damage [ø,å] |
| Laminaran | Branched (soluble) and unbranched (unsoluble) polysaccharide: beta 1-3,beta 1-6-glucan [å,β]. 84-94 % sugar and 6-9 % uronic acid [α] | *Laminaria digitata*: 14 % [g]<br>*Laminaria* sp. [i]: 99 % of total sugars [α]<br>*Fucus vesiculosis*: 84 % of total sugars [α]<br>*Ascophyllum nodosum*: 4.5 % [g];90 % of total sugars [α]<br>*Undaria pinnatifida* 3 % [f] | Only found in brown seaweed [a] |
| Phycarine | | *Laminaria digitata* [o] | Immune system, stimulation of macrophage phagocytosis [δ] |
| Porphyran | Polysaccharide: polymer of acidic saccharide containing sulphate groups, β-1,3-xylan [$] | *Porphyra umbilicalis*: 48 % [g]<br>*Porphyra* sp. [$] | Potential apopototic/programmed cell death activity [$] |
| Ulvan | Polysaccharide, highly branced polymers of soluble dietary fiber and contain rhamnose, glucuronic acid and xylose [μ,π]. Structurally similar to the mammalian glycosaminoglycans [ω] | *Ulva lactuca* [ω] | Cytotoxicity and cytostaticity, HU colon cell line [ω] |

a= (Murata and Nakazoe, 2001), b= (Ye et al., 2008), c= (Athukorala et al., 2007), d=(Amano et al., 2005), e= (Ghosh et al., 2009), f= (Je et al., 2009), g= (MacArtain et al., 2007), h= (Bartsch et al., 2008a), i= (Dietrich et al., 1995), j= (Yan et al., 2004), k= (Zhou et al., 2006a), l= (Skoler-Karpoff et al., 2008), m= (FAO, 2008), n= (Vlieghe et al., 2002), o= (Nishino et al., 1994), p= (Hemmingson et al., 2006), q= (Matsubara et al., 2005), r= (Marais and Joseleau, 2001), s= (Lee et al., 2004), t= (Maruyama et al., 2007), u= (Yamamoto et al., 1984), v= (Schaeffer and Krylov, 2000), x= (Mayer and Hamann, 2004), y= (Han et al., 2008), z= (Smit, 2004), æ= (Zubia et al., 2008), ø= (Gessner, 1971), å= (Lobban and Harrison, 1994), α= (Rioux et al., 2007), β= (Deville et al., 2007), δ= (Mayer et al., 2007), $= (Plaza et al., 2008), ω=(Kaeffer et al., 1999), μ= (Bobin-Dubigeon et al., 1997), π= (Michel and Macfarlane, 1996)



Boston architects Howeler + Yoon and Los Angeles digital designers Squared Design Lab have designed a conceptual structure for Boston, where an unfinished building would be covered in modular pods growing algae for biofuel. The pods would be continuously rearranged by robotic arms (powered by the micro-algae produced) to ensure the optimum growing conditions for alage in each pod. The designers intend to use the structure, called Eco-pods, to inform the public about the potential of micro-algae, a bio-fuel that can be grown vertically.
The pods could also house research projects.
The designers hope that the temporary nature of the structure would lead to many being placed around Boston, installed on suspended construction sites and areas particularly hit by the recession. www.raddblog.wordpress.com/category/economy/page/4/



# Seaweed network in Denmark


Tang som food og non-fo
Invitation til tangnetværksmøde
**mandag d. 23. marts kl. 16**
DTU Aqua
Søltoft plads bygning 221,
lokale 237 (2. sal)
2800 Kgs. Lyngby
16.00 Velkomst
Præsentationsrunde af fremmø
Tang i køkkenet
Ole G. Mouritsen
Forfatter og professor SDU
Dansk tang i helsekost
Torben Sønnichsen
Bioliving
Den gode kemi i tang
Susan L. Holdt
DTU Aqua
Plantestoffer og Sundhed
Hvad arbejder de med på Institut for Kemi-, Bio- og Miljøteknologi, SDU
Xavier Fretté/Bent Lyager
ca. 18.00 En lille anretning og snak

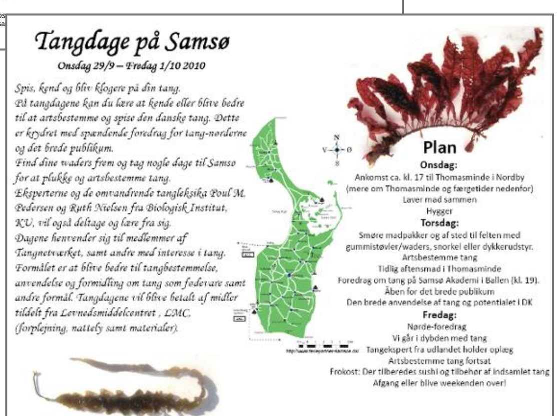
177 members from industry, universities, restaurants, organizaions, and persons that work with or have interest in seaweed

The network started in winter 2008

4 meetings and 4 newsletters

Some fundings from LMC: Levnedsmiddelcentret

Interested go to
www.akvakultur.dk
email
susan@akvakultur.dk


*Tangdage på Samsø*
*Onsdag 29/9 – Fredag 1/10 2010*
*Spis, kend og bliv klogere på din tang.*
*På tangdagene kan du lære at kende eller blive bedre til at artsbestemme og spise den danske tang. Dette er krydret med spændende foredrag for tang-nørderne og det brede publikum.*
*Find dine waders frem og tag nogle dage til Samsø for at plukke og artsbestemme tang.*
*Eksperterne og de omvandrende tangleksika Poul M. Pedersen og Ruth Nielsen fra Biologisk Institut, KU, vil også deltage og lære fra sig.*
*Dagene henvender sig til medlemmer af Tangnetværket, samt andre med interesse i tang.*
*Formålet er at blive bedre til tangbestemmelse, anvendelse og formidling om tang som fødevare samt andre formål. Tangdagene vil blive betalt af midler tildelt fra Levnedsmiddelcentret, LMC.*
*(forplejning, nattely samt materialer).*
**Plan**
**Onsdag:**
Ankomst ca. kl. 17 til Thomasminde i Nordby
(mere om Thomasminde og færgetider nedenfor)
Laver mad sammen
Hygger
**Torsdag:**
Smøre madpakker og af sted til felten med gummistøvler/waders, snorkel eller dykkerudstyr.
Artsbestemme tang
Tidlig aftensmad i Thomasminde
Foredrag om tang på Samsø Akademi i Ballen (kl. 19).
Åben for det brede publikum
Den brede anvendelse af tang og potentialet i DK
**Fredag:**
Nørde-foredrag
Vi går i dybden med tang
Tangekspert fra udlandet holder oplæg
Artsbestemme tang fortsat
Frokost: Der tilberedes sushi og tilbehør af indsamlet tang
Afgang eller blive weekenden over!