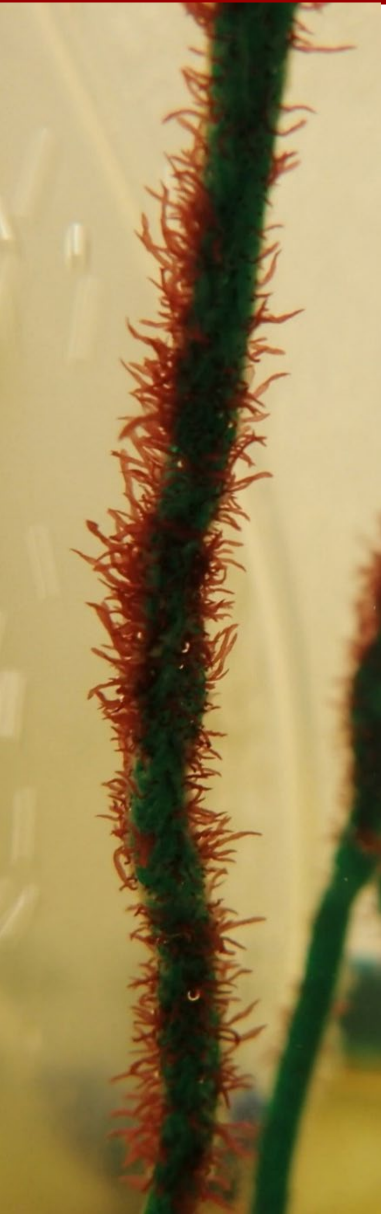

Updated cultivation methods for *Palmaria palmata*

– new insights towards a reliable production

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- MSc. 2013 (AU)
  Kelp cultivation & nutrient uptake and salinity
- Kelp farmer 2013-2015
- PhD. 2020
  Palmaria palmata

- Background
- Life cycle
- Optimizing hatchery

DTU
DTU Aqua
National Institute of Aquatic Resources

NTNU
Norwegian University of Science and Technology

Investigating hatchery and cultivation methods for improved cultivation of *Palmaria palmata*

Peter Søndergaard Schmedes

PhD thesis, April 2020

Palmaria palmata

- High reputation - dried snack / unique taste
- Valuable contents - new applications
- Demands a scalable cultivation practice and optimized methods


Credit: Werner & Dring 2011

Cultivation workflow

Collection → Hatchery → Nursery → Cultivation → Harvest

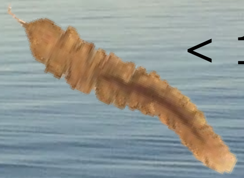
Bottlenecks

- High requirement of spore donors for substrate seeding
- Only one seeding method with short window
- Variable seeding quality and loss of spores

Hatchery seeding method based on gravity - works, but is in-efficient

Requirement of spore donor tissue (kg/t FW harvest)

~ 72 kg FW/t FW harvest



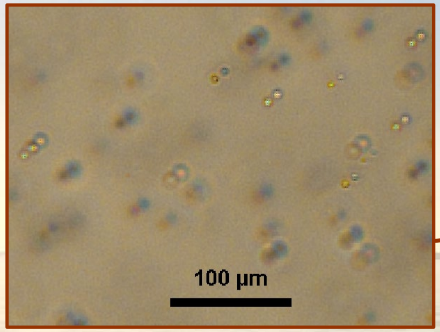
< 1 kg FW/t FW harvest

Life cycle of P. palmata

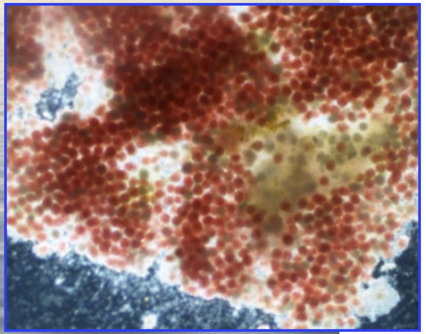
❑Basics for hatchery improvement

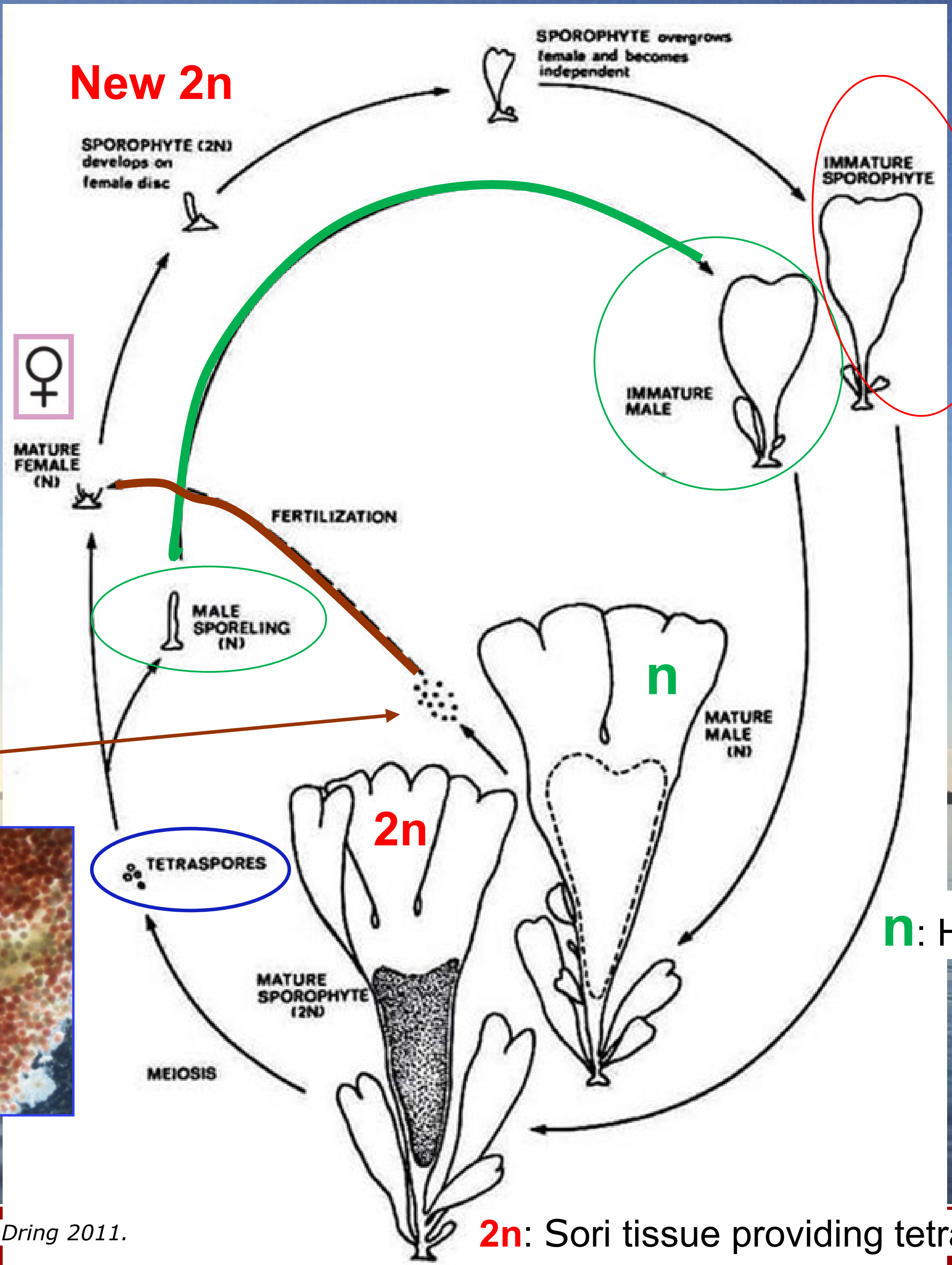
In the hatchery

- Spore dispersal vs. aggregates
- Fertilization improves spore use



Male gametes in sea water



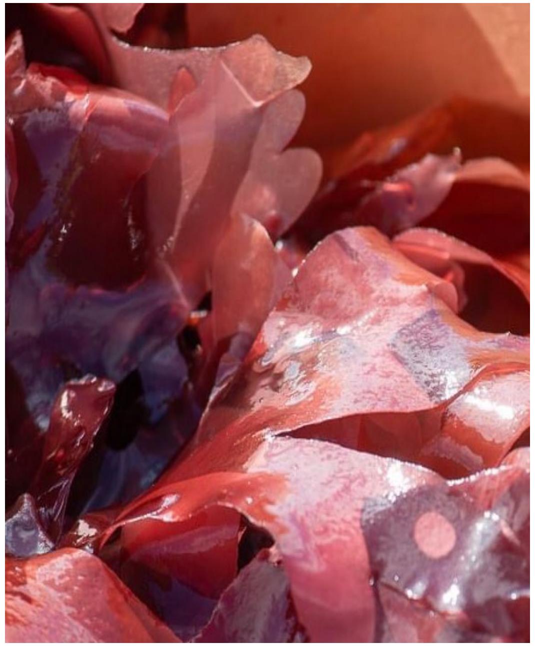


n: Haploid male gametophyte

2n: Sori tissue providing tetraspores

Backwards review of challenges related to the cultivation work flow

Collection → Hatchery → Nursery → Cultivation → Harvest



✓ **Harvest**

Sufficient harvest yield of clean biomass

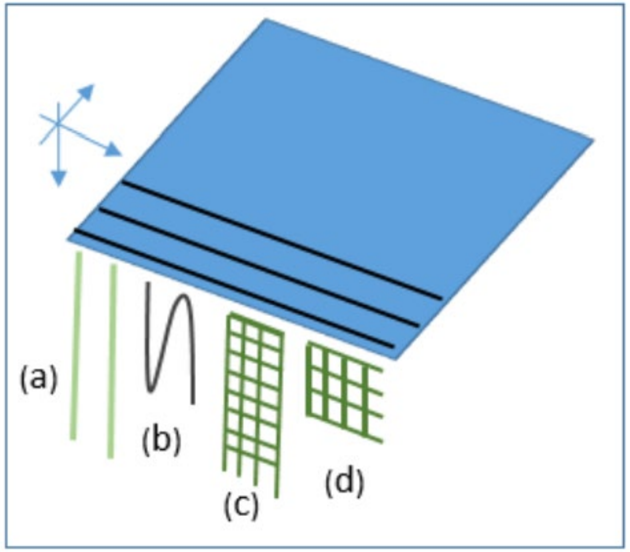
Backwards review of challenges related to the cultivation work flow

Collection → Hatchery → Nursery → Cultivation → Harvest

Longline system

Deployments:

(a) Single droppers
(b) Loops
(c) Vertical net
(d) Horizontal net



- ✓ **Cultivation**
  - Deployment unit (rope, net, sheet)
  - High specific biomass yield
  - Ease of handling (hatchery, deployment, harvest)
- ✓ **Harvest**
  - Sufficient harvest yield of clean biomass

Backwards review of challenges related to the cultivation work flow

Collection → Hatchery → Nursery → Cultivation → Harvest

? Nursery ?

Optimal density of seedlings (10-50 cm^{-1}) ~ seeding density (20-100 spores cm^{-1})
Seedling size (0.5-4 cm) ~ duration

✓ Cultivation

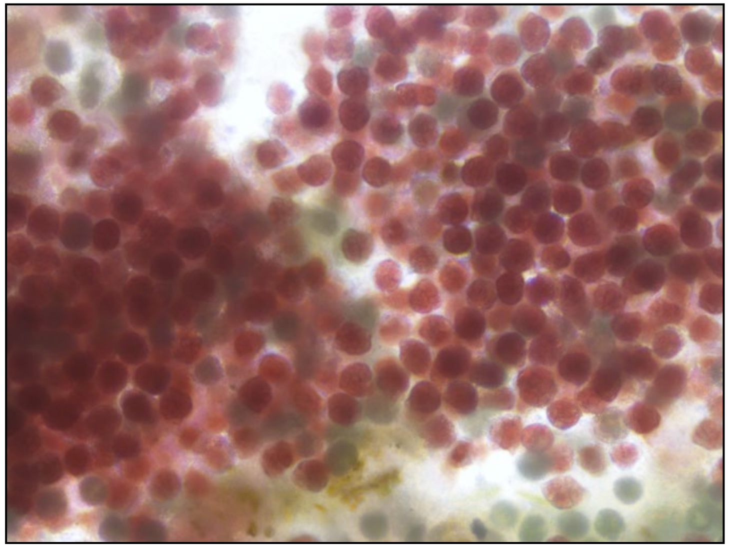
Deployment unit (rope, net, sheet)
High specific biomass yield
Ease of handling (hatchery, deployment, harvest)

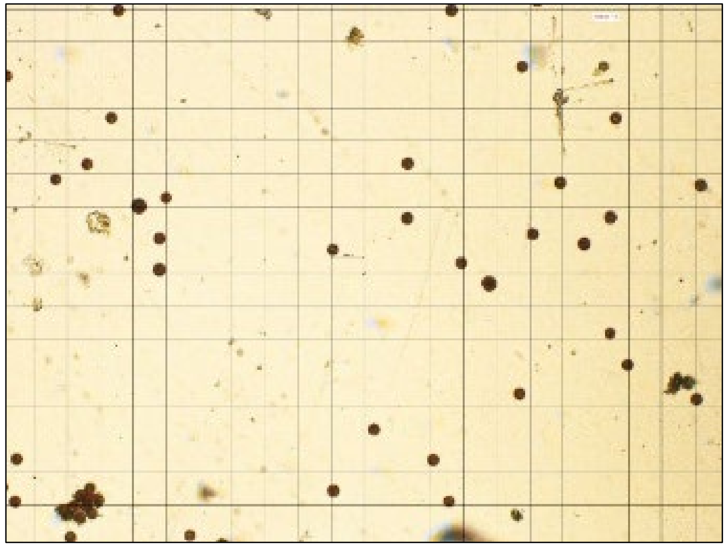
✓ Harvest

Sufficient harvest yield of clean biomass

Backwards review of challenges related to the cultivation work flow

Collection → Hatchery → Nursery → Cultivation → Harvest





? Hatchery seeding ?

Timing of spore release and spore yield ~ duration ?

Even spore settlement ~ seeding method (sori vs propagules) ?

? Nursery ?

Optimal density of seedlings (10-50 cm^{-1}) ~ seeding density (20-100 spores cm^{-1})
Seedling size (0.5-4 cm) ~ duration

✓ Cultivation

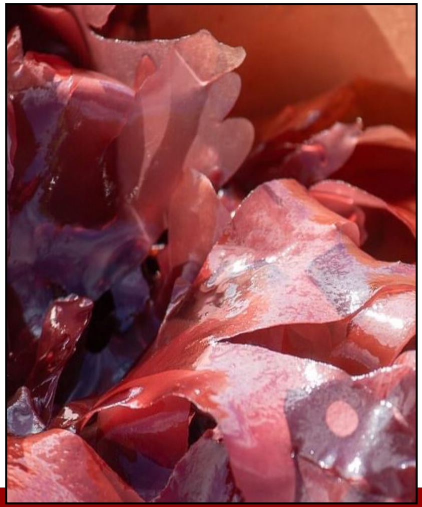
Deployment unit (rope, net, sheet)
High specific biomass yield
Ease of handling (hatchery, deployment, harvest)

✓ Harvest

Sufficient harvest yield of clean biomass

Backwards review of challenges related to the cultivation work flow

Collection → Hatchery → Nursery → Cultivation → Harvest



? Collection of spore donors ?

Timing of season, sporophyte recognition?

? Hatchery seeding ?

Timing of spore release and spore yield ~ duration ?

Even spore settlement ~ seeding method (sori vs propagules) ?

? Nursery ?

Optimal density of seedlings (10-50 cm^{-1}) ~ seeding density (20-100 spores cm^{-1})
Seedling size (0.5-4 cm) ~ duration

✓ Cultivation

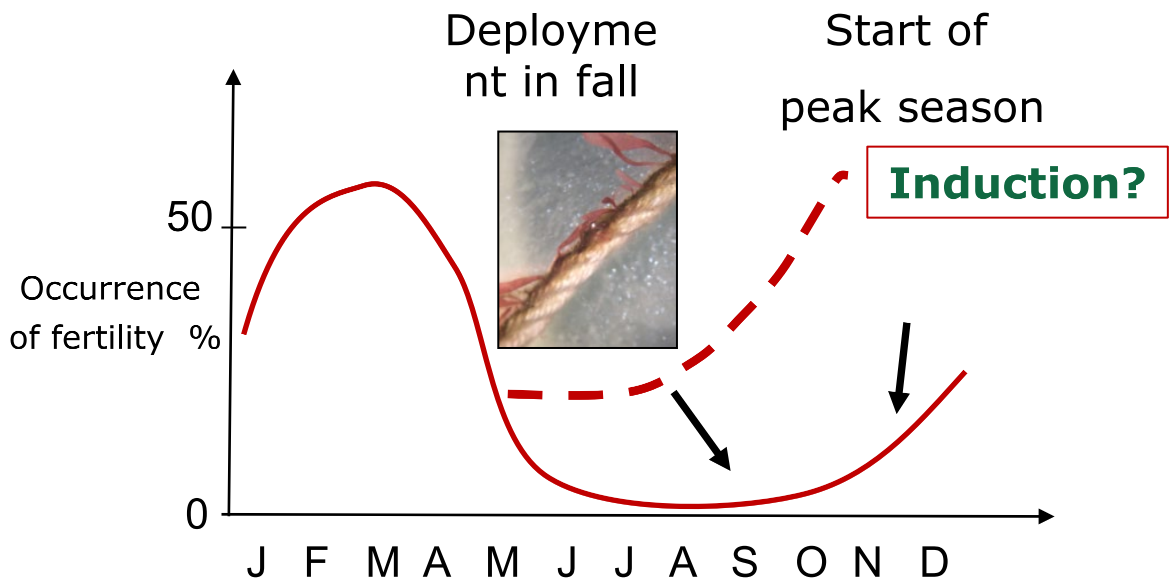
Deployment unit (rope, net, sheet)
High specific biomass yield
Ease of handling (hatchery, deployment, harvest)

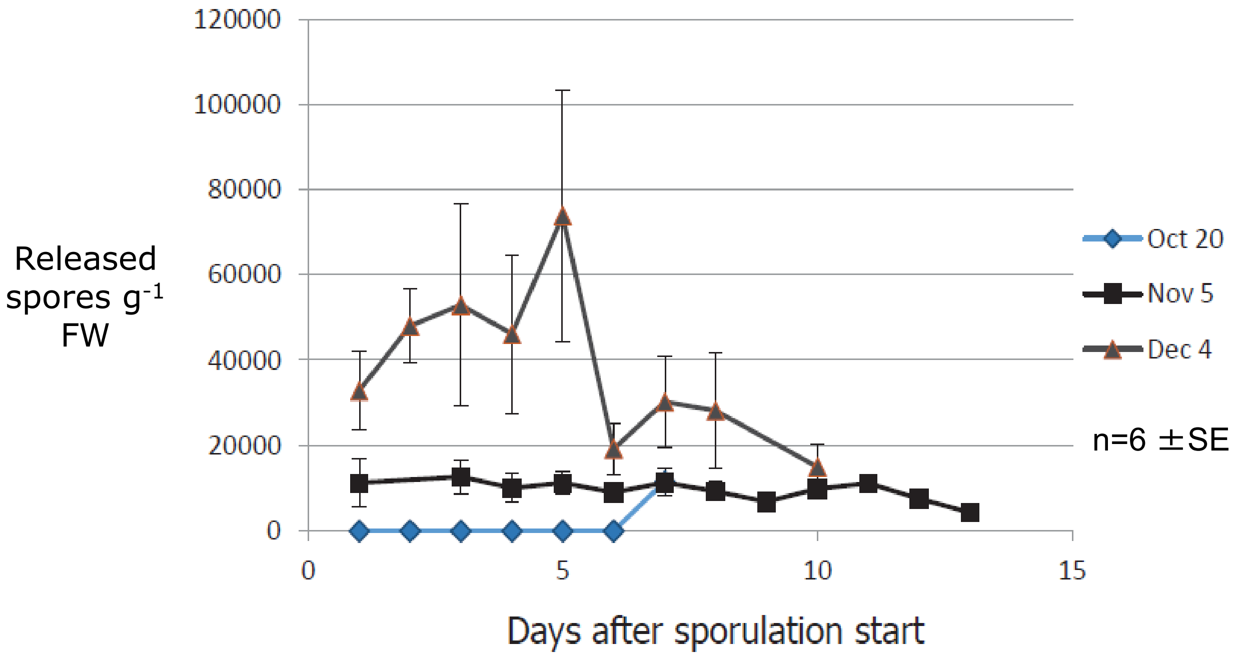
✓ Harvest

Sufficient harvest yield of clean biomass

Collection

Seasonality in reproduction
How to secure access to spore donors?

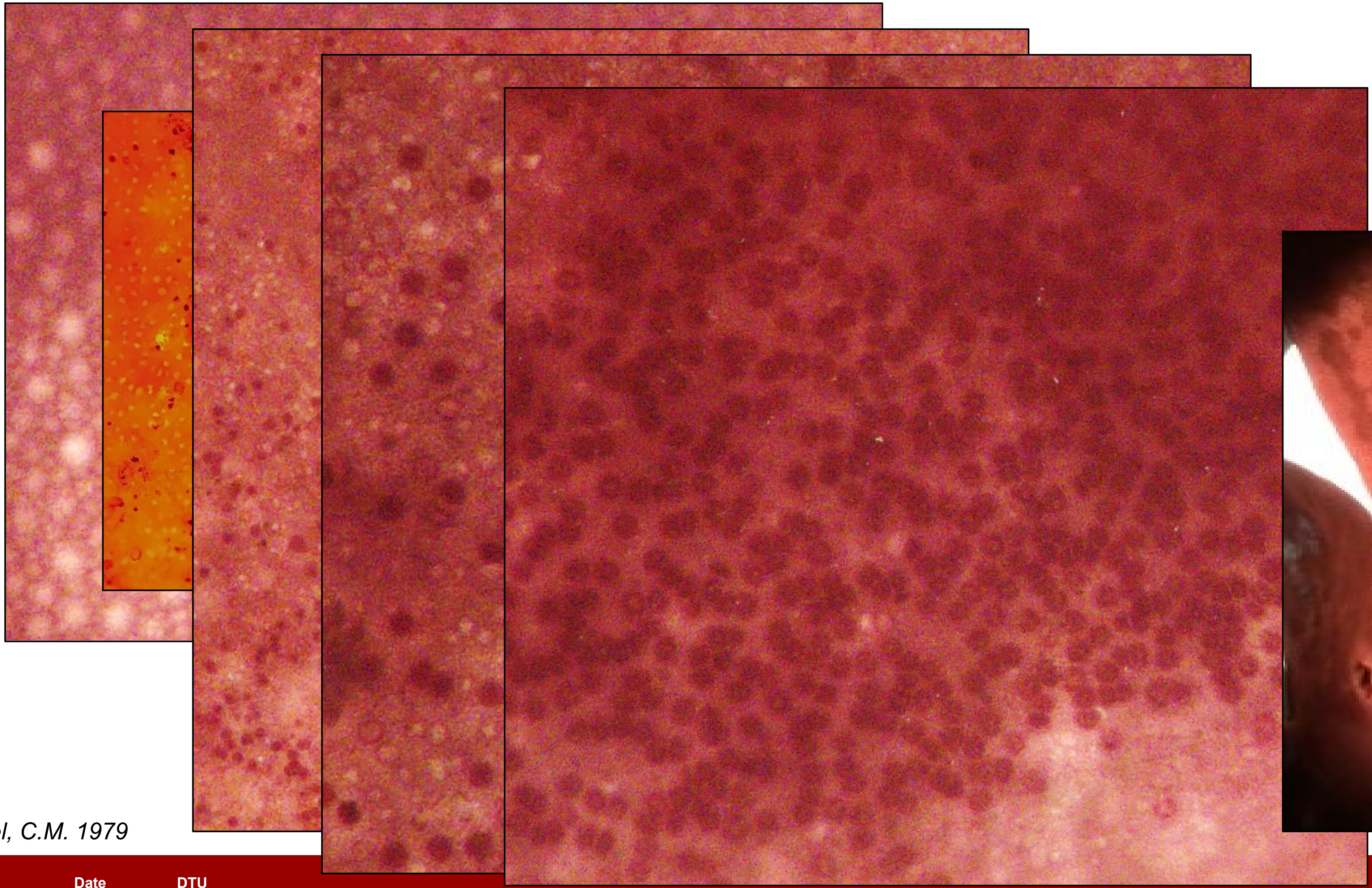


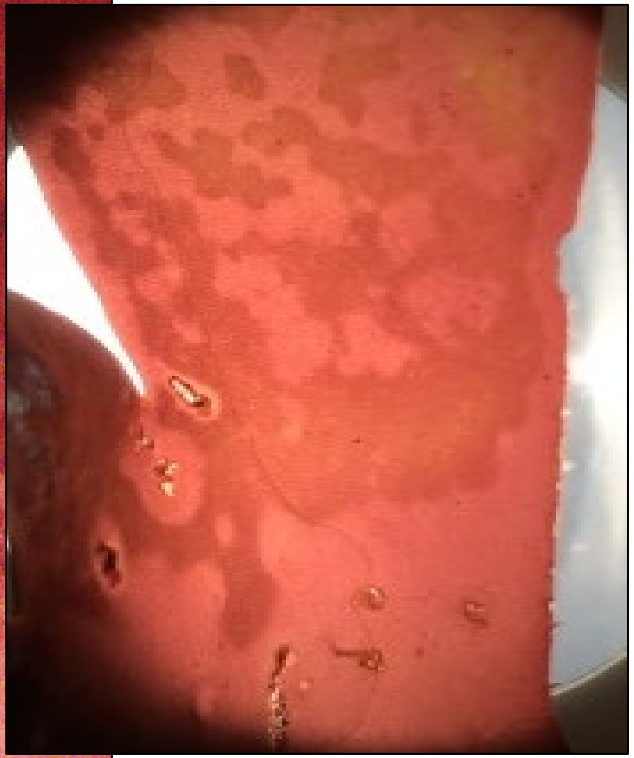


- Germination and development of seedlings require 1-3 months to reach a size min. 5 mm
- **Manipulating env. parameters – but the response time is still long – induction not yet effective stategy!**
- **Accelerate/pause sporangia maturation**

Identifying sporophyte and male gametophyte
Sporangial initials in the cortex layer

2n or n?





Pueschel, C.M. 1979

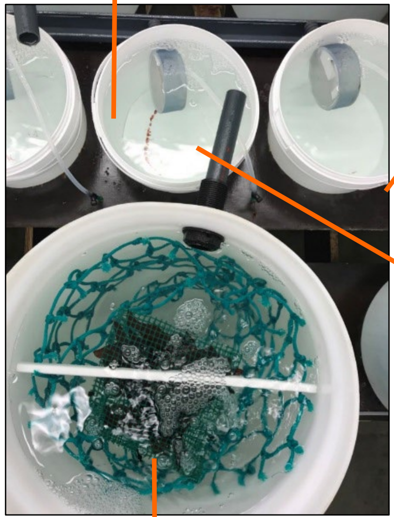
Hatchery Seeding

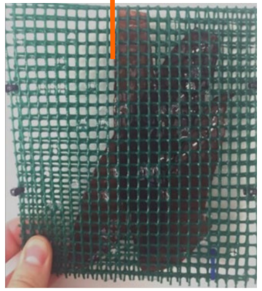
Focus on improving spore use efficiency in hatchery seeding

- ✓ Less spore donors
- ✓ Better dispersal
- ✓ Improve survival

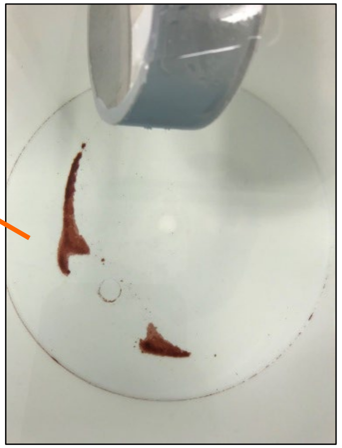
Tumble flow-through

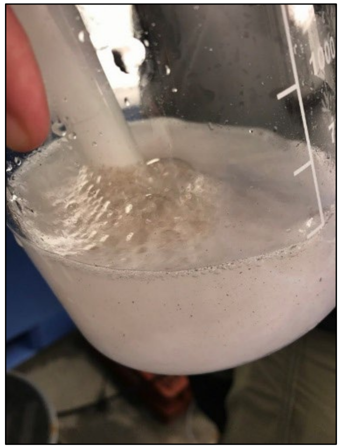
Retain ”effluent spores”



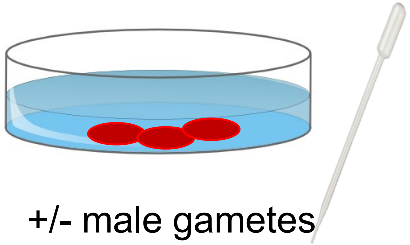


- Count spores + seedlings (day 3,19, 32)
- Net seeding efficiency = $spores_{NET}$ / ($spores_{NET\ +\ EFFLUENT}$)

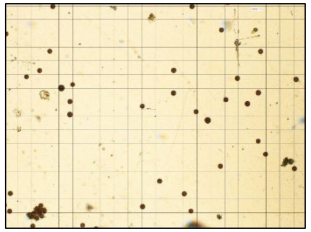




Include fertilization

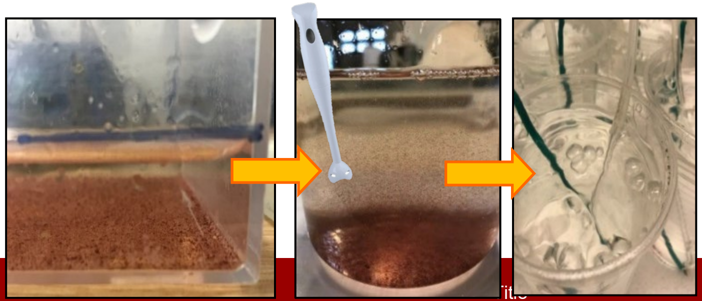


+/- male gametes



- Packages with increasing amount of spore donors i.e., 5, 10, 15 gFW
- Re-use: Seeded 3 nets during 9 days (3 days each)

Germination **M**aceration **A**gitation



Hatchery Seeding

Results on hatchery seeding

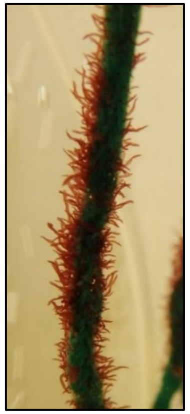
Flow-through seeding

- Net seeding efficiency = 16 %
- Even spore settlement (day 3)
- 9 seedling cm^{-1} after 32 days

- Nursery duration of 1 vs. 9 months

GMA-seeding ropes

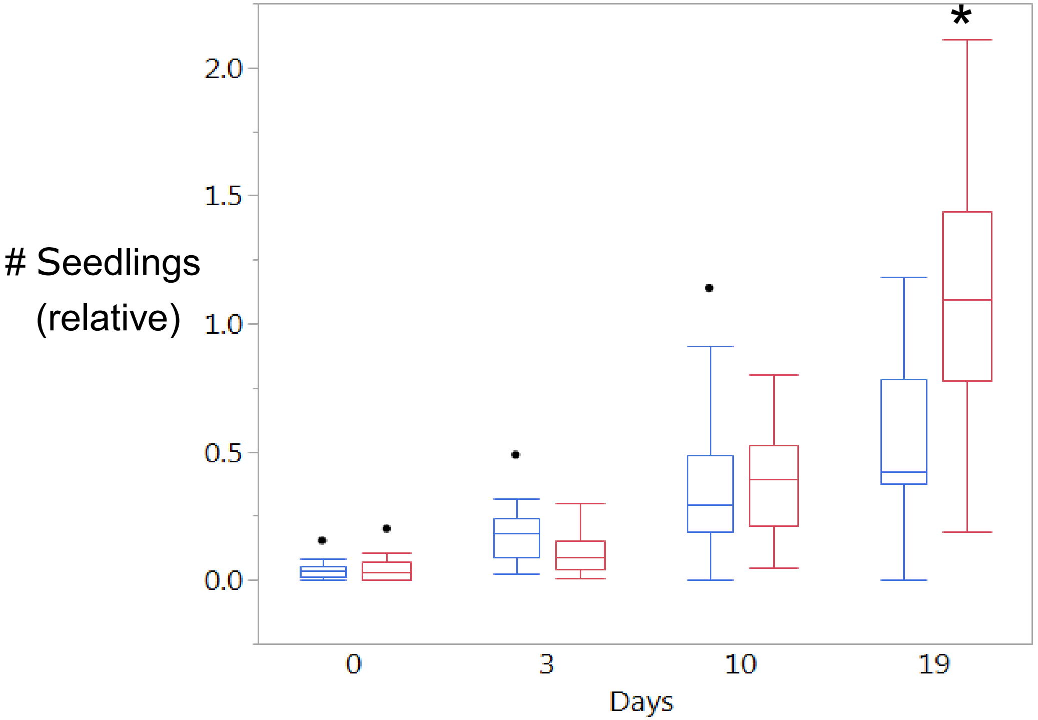
- Succesful re-attachment for germlings detached at day 29 and 39 (not day 240)
- 60 seedlings cm^{-1} (high concentration used)



- Nursery duration of 9 months (density lowered)

Fertilization step

- Higher seedling density on day 20 (activation of females)



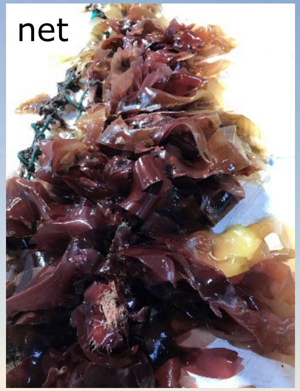
(*Schmedes et al., 2019, Alg Res; Schmedes & Nielsen, JAPH, 2019*)

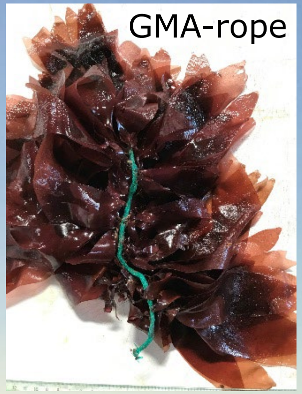
Cultivation

Biomass yields from a cultivation trial

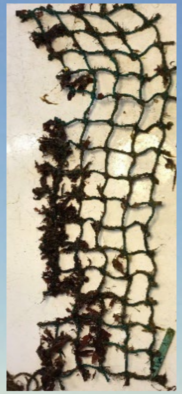
9 months nursery

1. Harvest 2020 (cropping)





Over-summering



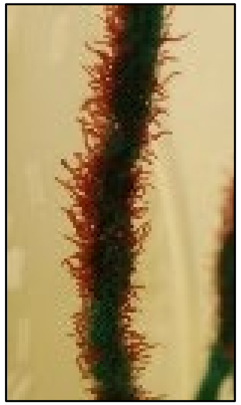
2. Harvest 2021 (cropping)

Substrate	Harvest year	Cultivation depth (m)	Avr. biomass yield kgFW/m longline	Max. yield kgFW/m longline
Net	2020	1.5	2.9 kg (n=3)	4.9 kg (n=1)
GMA-rope	2020	1.5	1.6 kg (n=3)	1.7 kg
Net	2021	1.5	2.4 kg (n=3)	2.8 kg
Total (nets)			**5.3 kg (n=3)**	**7.7 kg (n=1)**

Perspectives for upscaling hatchery production

- ❑ Several ways to improve hatchery production of Palmaria palmata

- ➢ Increase hatchery seeding efficiency (m substrate / g spore donor tissue) ~ minimum or re-use
- ➢ Optimize spore settlement distribution ~ substrate feature & spore dispersal
- ➢ Maximize spore survival ~ activate female gametophytes & water quality & alternative seeding (GMA)



- ❑ Compare seeding efficiency of two different seeding methods:

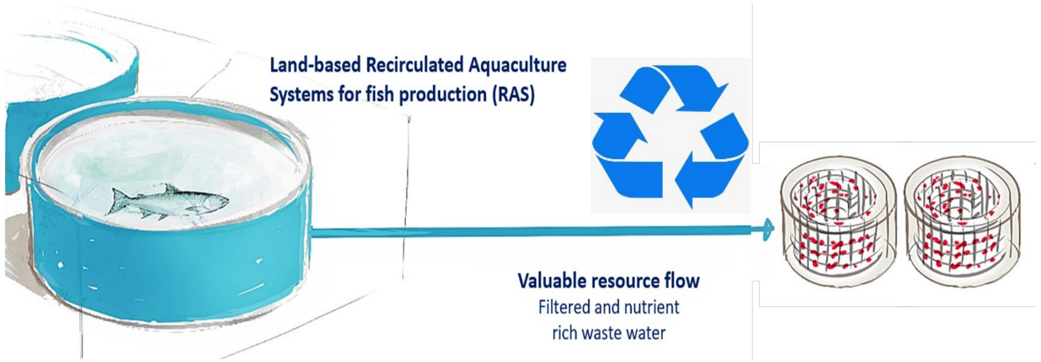
- ○ The horizontal gravity-based (Dring & Werner 2011)
  - ➢ 23g/m substrate (1.8 kg FW fertile sporophytes to seed a net eqivalent to 82 m rope)
    → 136 kg FW fertile sporophytes to seed enough nets for 100 m longline deployment

- ○ Vertical flow-though seeding system (Schmedes 2020)
  - ➢ 0.1-0.3 g/m substrate (5-15 g FW fertile sporophytes to seed a net eqivalent to 46 m rope)
    → 0.6-2 kg FW fertile sporophytes to seed enough nets for 100 m longline deployment
  - ➢ **Improvement of factor 68-224 in hatchery seeding efficiency**

Landbased palmaria cultivation - why?

- It is worth the effort – high market prices
  - One of the most valued seaweed species for food
    - » Prices up to **250 € per kg** (dry)

- Provides extra possibilities
  - Higher control → **high quality**
  - Integrated **multi-species culture** practise
    - » Nutrient removal/nutrient re-use
    - » Green branding

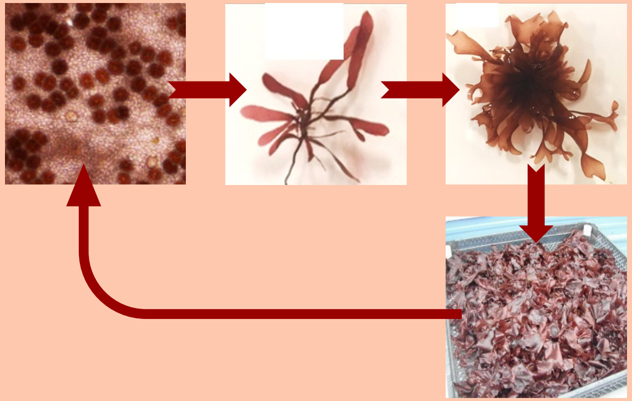


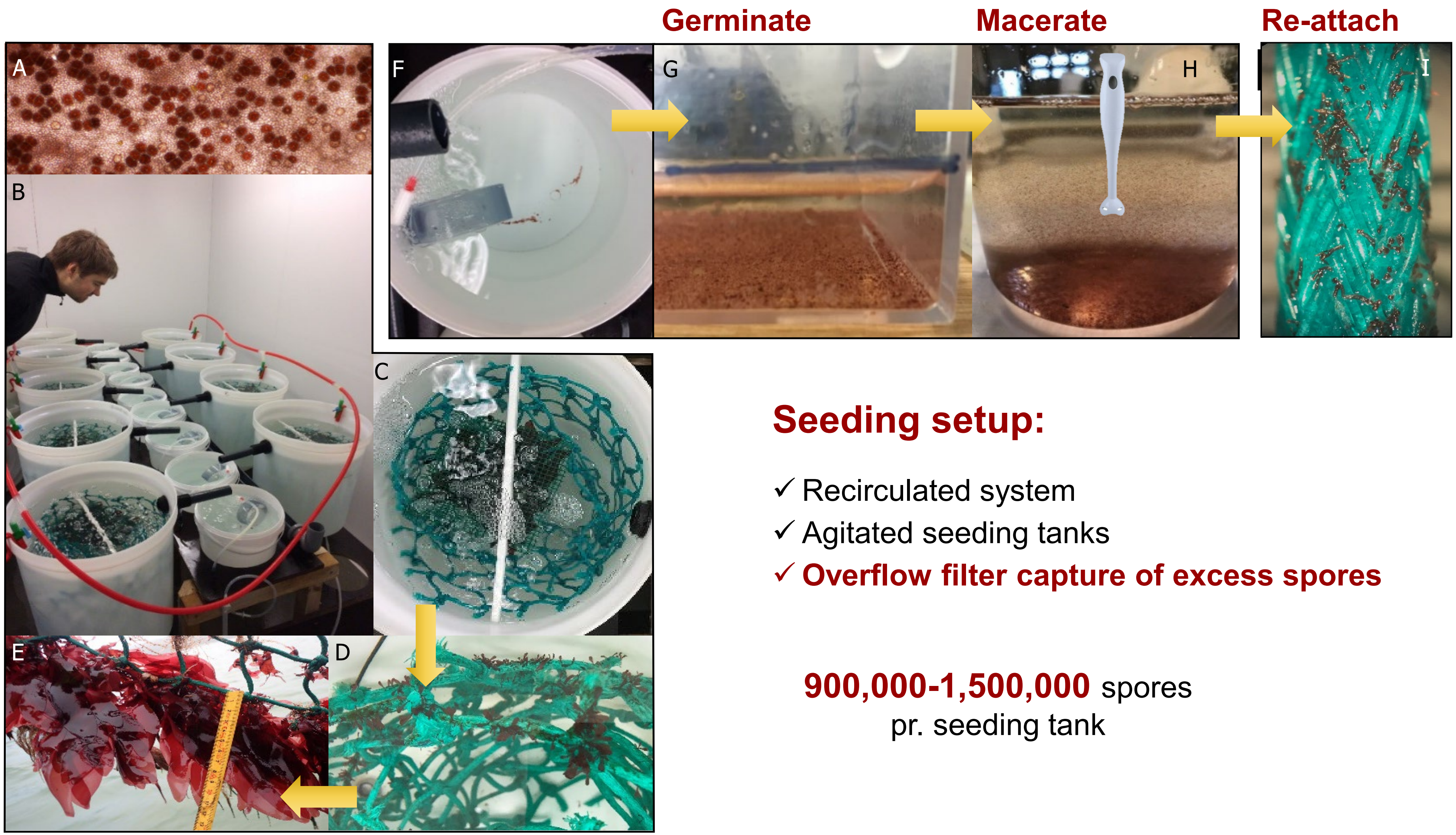
Propagation of **wild** harvested biomass

- Vegetative growth
- Easy to operate
- Starter culture from wild resources
  - Frequent (pr. season)
  - Renewal

Spore-based propagation

- DK: Lack of hard substrate
  Wild beds are difficult to access
- Sustainability (less impact on wild stocks)
- Starter culture from wild
  - Potentially independent in future



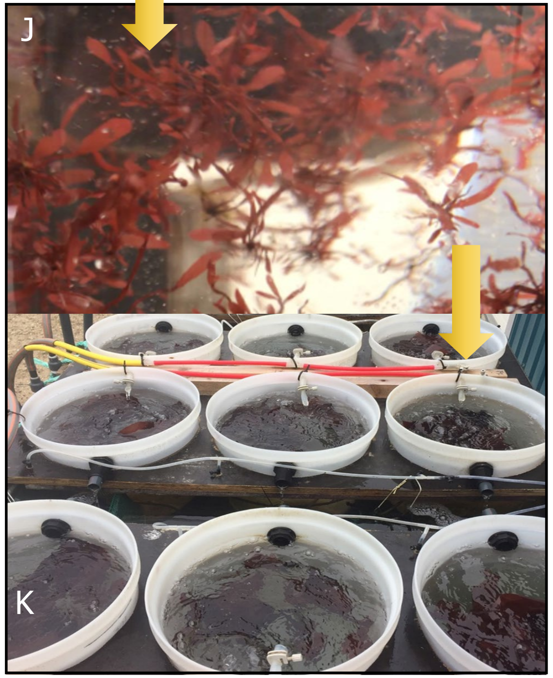


Seeding setup:

- ✓ Recirculated system
- ✓ Agitated seeding tanks
- ✓ **Overflow filter capture of excess spores**

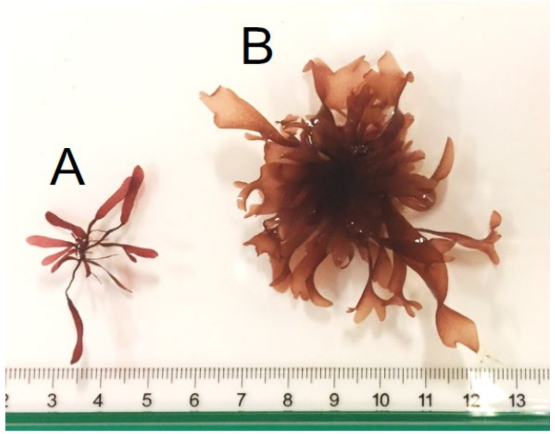
900,000-1,500,000 spores
pr. seeding tank

Germinate Macerate Re-attach



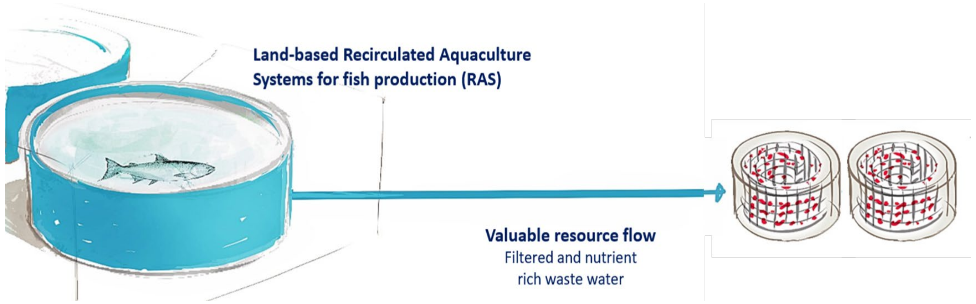
Seedling bank:

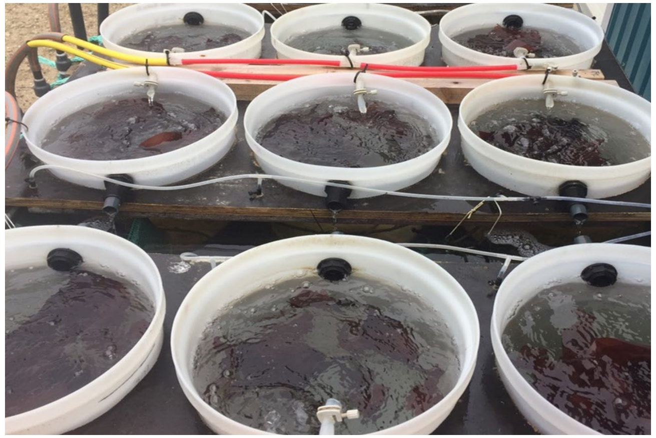
Possible to keep at ”*skeleton scale”* for minimum 3 years at low maintenance



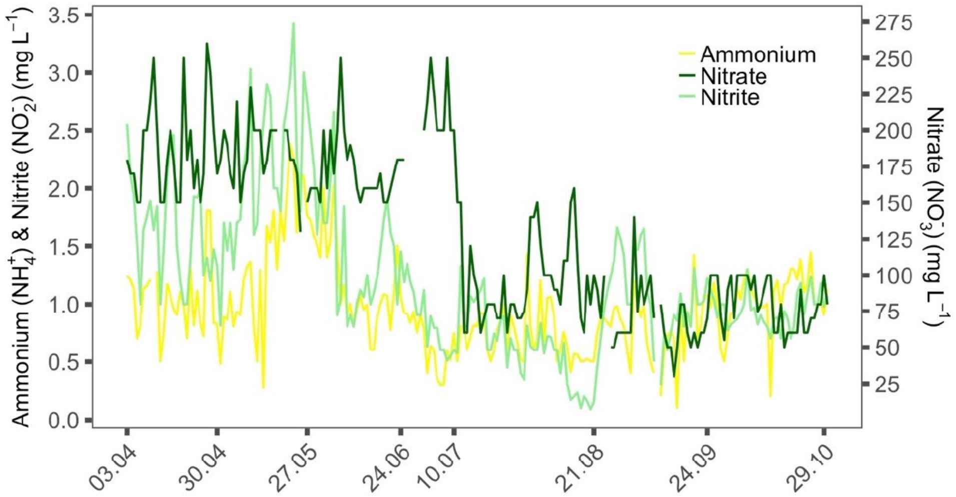
Master project: Jørgen Levinsen

Cultivation of *Palmaria palmata* in land-based IMTA systems





Flow through bubbling tanks (30 l) with process water from landbased salmon farm.



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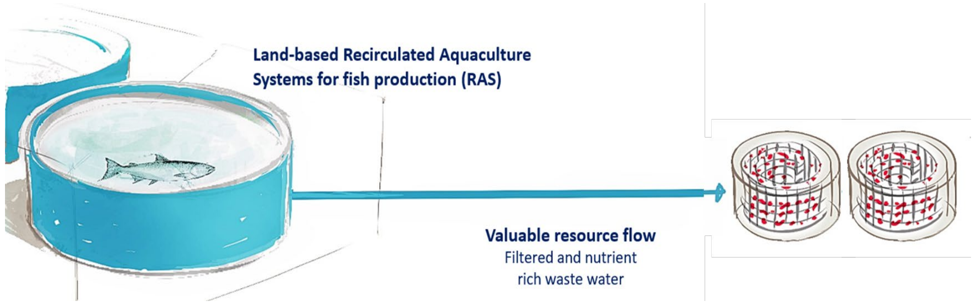

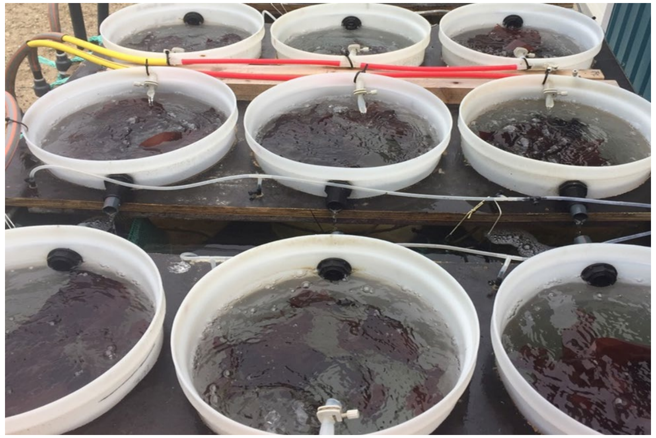

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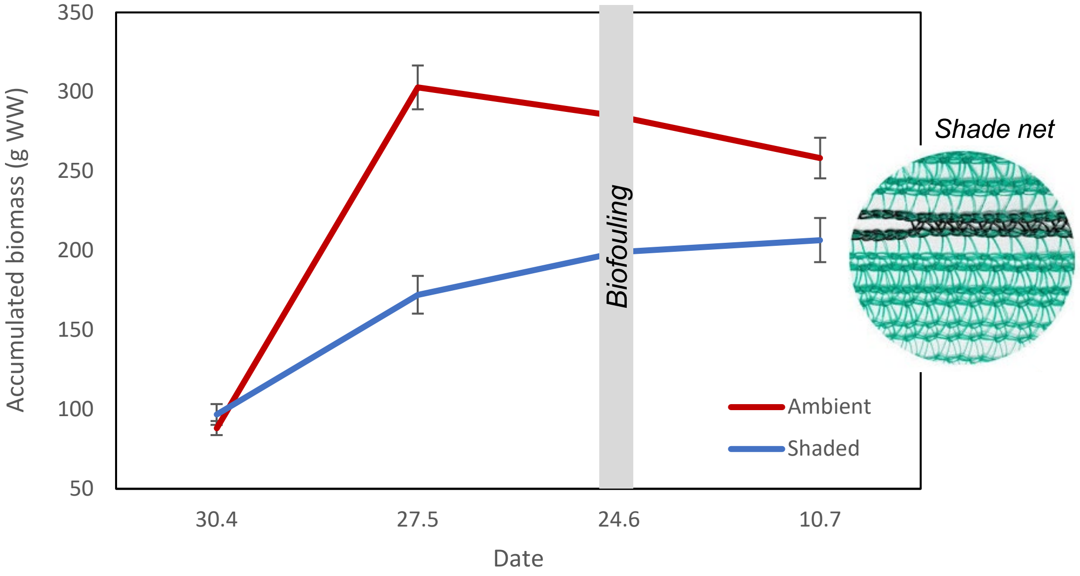
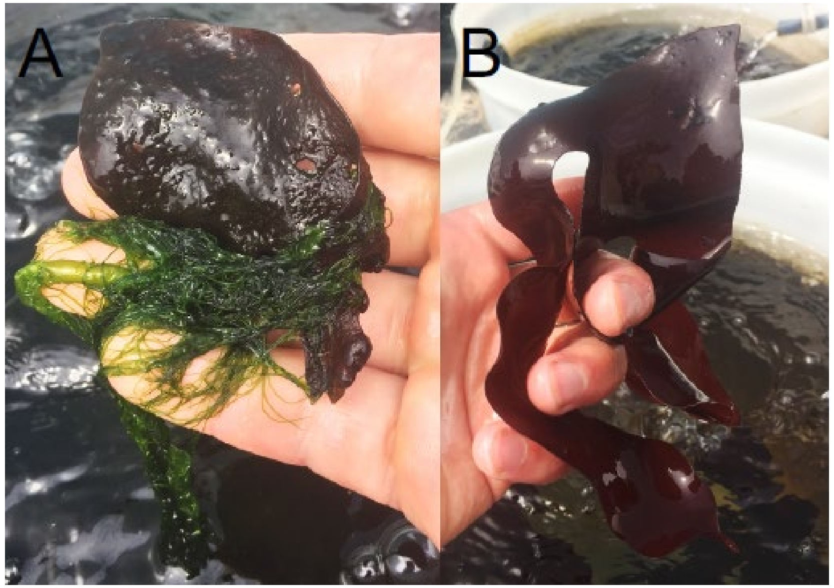
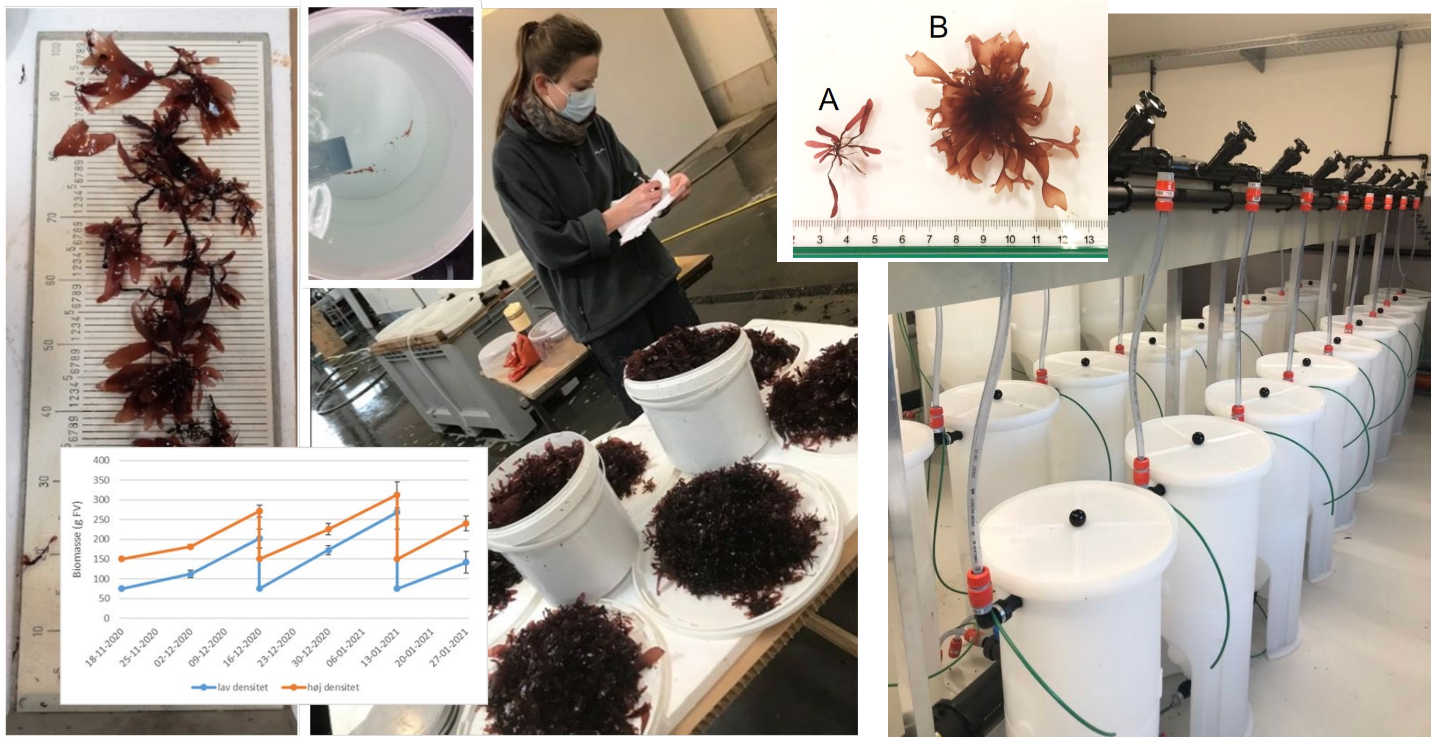




Ambient *Shaded*

DTU



Current research:

- Light (e.g. red light to reduce fouling)
- Nutrients (e.g. pulse)
- Density
- Salinity (e.g. low/fluctuating salinity tolerance)
- Maintenance (man power need)
- Fouling control (e.g. chemical, ”environmental” triggers)

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https://doi.org/10.1007/s10811-020-02248-4

Productivity and growth rate in *Palmaria palmata* affected by salinity, irradiance, and nutrient availability—the use of nutrient pulses and interventional cultivation

Peter Søndergaard Schmedes[1,2] · Mette Møller Nielsen[1]

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Abstract
Land-based cultivation of the rhodophyte *Palmaria palmata* is promising for high productivity and nutrient mitigation, yet the cultivation strategy and the knowledge of the effect of various environmental factors are incomplete. In a two-phased cultivation trial, marginal proliferations were used as seedstock to test the impact of irradiance (10–280 µmol photons $m^{-2} s^{-1}$ photosynthetically active radiation; PAR) using sequential nutrient phases of pulse additions (10% vs. 100% F/2+) on specific growth rate (SGR) and productivity (exp.1). The effect of salinity (15–35‰) and nutrient concentration (10 vs. 100% F/2+) on frond growth was investigated (exp.2). The SGR peaked at 200 µmol photons $m^{-2} s^{-1}$ PAR in both nutrient phases with max mean SGR of 6.86 ± 0.4% day^{-1} (mean ± SE, $n = 3$). Above 80 µmol photons $m^{-2} s^{-1}$ PAR, thalli turned pale green after 3 weeks at low nutrient. Shifting to a high nutrient cultivation, thalli recovered their red color after 10 days, even at 280 µmol photons $m^{-2} s^{-1}$ PAR and significantly upshifted SGR, dry matter (DM), nitrogen (N), phosphorous (P), and ash content by 79.3, 56.0, 27.3, and 16.4%, respectively. Peak productivity in DM (1.17 g DM $m^{-2} day^{-1}$), carbon (C) (406.41 mg C $m^{-2} day^{-1}$), N (20.61 mg N $m^{-2} day^{-1}$), and P (2.06 mg P $m^{-2} day^{-1}$) coincided with SGR. Salinity significantly affected SGR of *P. palmata* and peaked at 15‰. This study highlights the use of marginal proliferations seedstock, nutrient pulses, and intervention practice for biomass propagation of *P. palmata* while avoiding epiphytes to boost N removal.

Keywords Rhodophyta · Seedstock · RAS seaweed · Nutrient pulses · N-starvation · N-removal · Brackish salinity

Introduction

The rhodophyte seaweed *Palmaria palmata* (L.) F. Weber & D. Mohr is highly valued as nutritious snack food, known as dulse, and as a promising source of bioactive compounds for aquaculture feed, cosmetics, and nutraceuticals (Holdt and Kraan 2011; Mouritsen et al. 2013; Moroney et al. 2015; Lopes et al. 2019). Currently, the supply of *P. palmata* for commercial products is sourced by hand harvesting wild populations, which is time-consuming and raises increasing concerns on overexploitation of wild seaweed populations (Ugarte and Sharp 2001; Monagail et al. 2017). Increasing demand has prompted research on the cultivation of *P. palmata* to promote a reliable biomass supply (Martínez et al. 2006; Werner and Dring 2011; Schmedes et al. 2019; Schmedes and Nielsen 2020), reimbursed by the potential application of its derived bioactive hydrolysates (Harnedy et al. 2014; Beaulieu et al. 2016).

Like other marine rhodophyte seaweed species, *P. palmata* displays a high nutrient content accommodated by high nutrient uptake capacity for the synthesis of nutrient compounds (Morgan et al. 1980a; Morgan and Simpson 1981a). Hence, several rhodophytes have been suggested as good candidates to enhance nutrient resource utilization when cultivated in water from land-based marine fish farms or adjacent to sea-based farms, a process known as integrated multi-trophic aquaculture or IMTA (Haglund and Pedersen 1992; Chopin et al. 2001; Neori et al. 2004; Sanderson 2006; Abreu et al. 2011; Corey et al. 2013; Grote 2019). The IMTA farming configuration provides high nutrient availability and stimulates the nutrient uptake, which has a positive effect on tissue pigmentation, light-induced stress tolerance, and seaweed productivity (DeBoer and Ryther 1977; Morgan and Simpson

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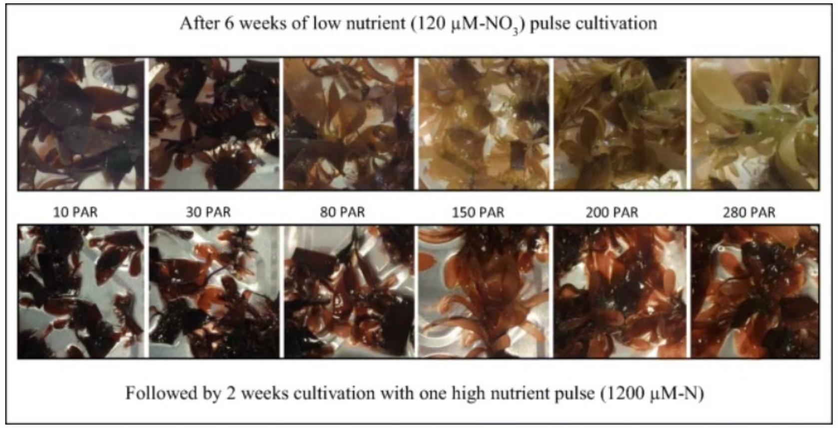
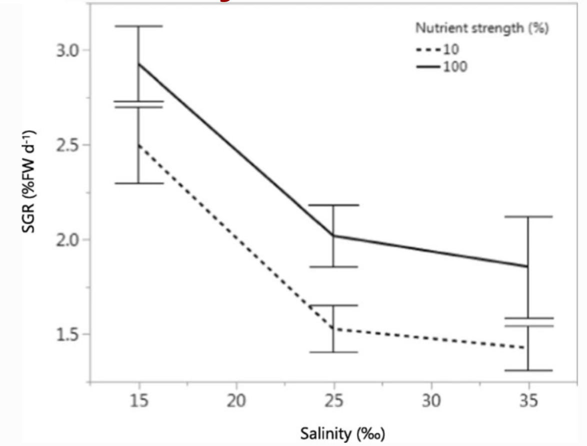
Nutrient pulse



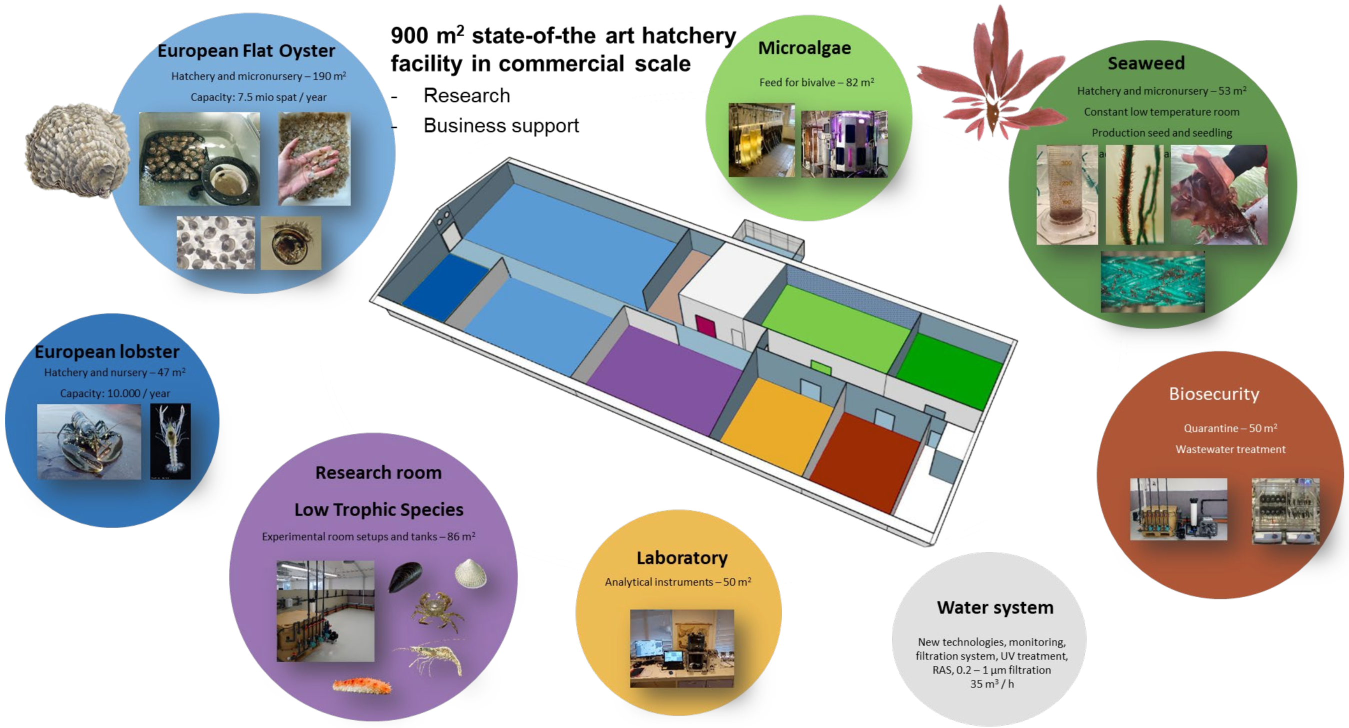
Salinity



New facility for increased control

- Research platform
- Business hub

900 m² state-of-the art hatchery facility in commercial scale
- Research
- Business support



New facility for increased control

- **Research platform**
- **Business hub**

FUTURE AMBITIONS

- Diversifying seaweed aquaculture
- Close contact with industry and start-up companies
- Demands for **hatchery development**
  - Innovation and technologies
  - Methodologies and protocols
  - **Species diversifiation**

Thanks for listening!

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