OPTIMISATION OF KELP (LAMINARIALES) CULTIVATION IN IRELAND: PRELIMINARY DATA FROM LABORATORY AND FIELD EXPERIMENTS

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There is wide-scale interest in developing intensive sea-cultivation of various macroalgae with the idea of supplying industry, with e.g. bioactive molecules or feed-stock for biofuel production, and in a sustainable way. In Europe much of the focus has centred on a variety of kelp species (Laminariales). Laminariales have a heteromorphic life-cycle alternating between microscopic small gametophytes and large sporophytes. For culture purposes the microscopic stages - release of zoospores, growth of gametophytes, gametogenesis, growth of juvenile sporophytes- are carried out in the laboratory, while the on-growing of sporophytes to maturity is carried out on longlines at sea. These processes are labour and time intensive and there is a need to improve their efficiency. Furthermore, there is very little data on productivity within Europe, although there has been much speculation about the potential.

Lab Stage 1: Collection of fertile material, induction of sporogenesis, culture of the zoospores / gametophytes.

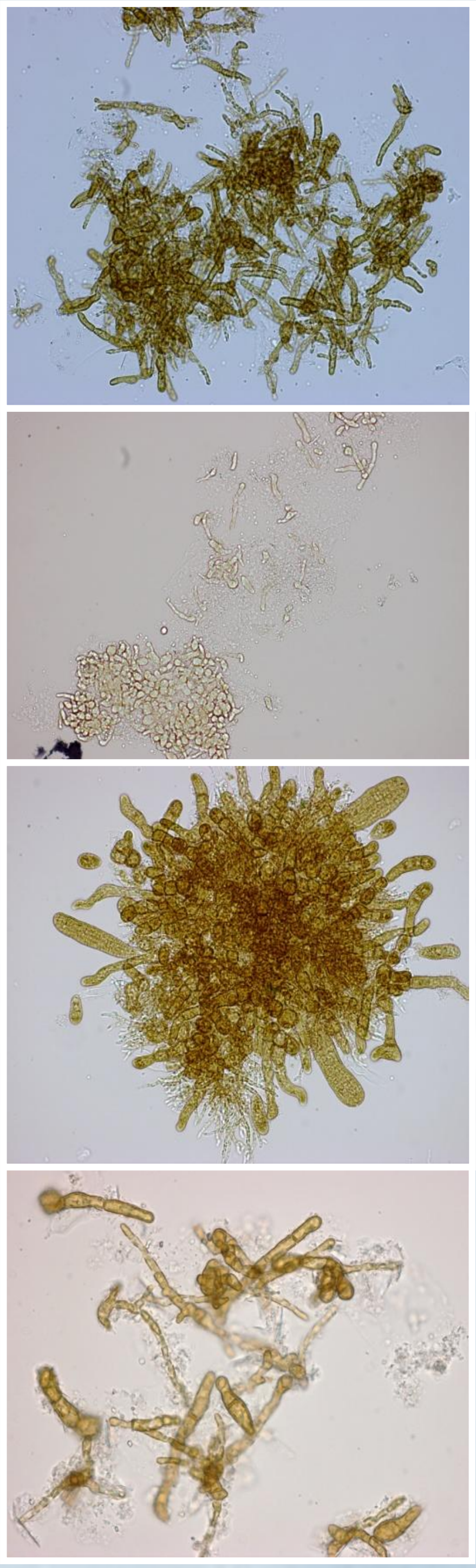
Cultures can be artificially maintained in a vegetative state, allowing control over when fertilisation is induced and therefore when young sporophytes begin their growth cycle. In the process the gametophyte culture can be 'bulked-up' in order to increase its biomass and consequently the amount of culture string that can be seeded. The following experiment aimed to begin the process of optimising the gametophyte culture stage for *Laminaria digitata*.

L. Digitata gametophyte growth: Experimental Set-up

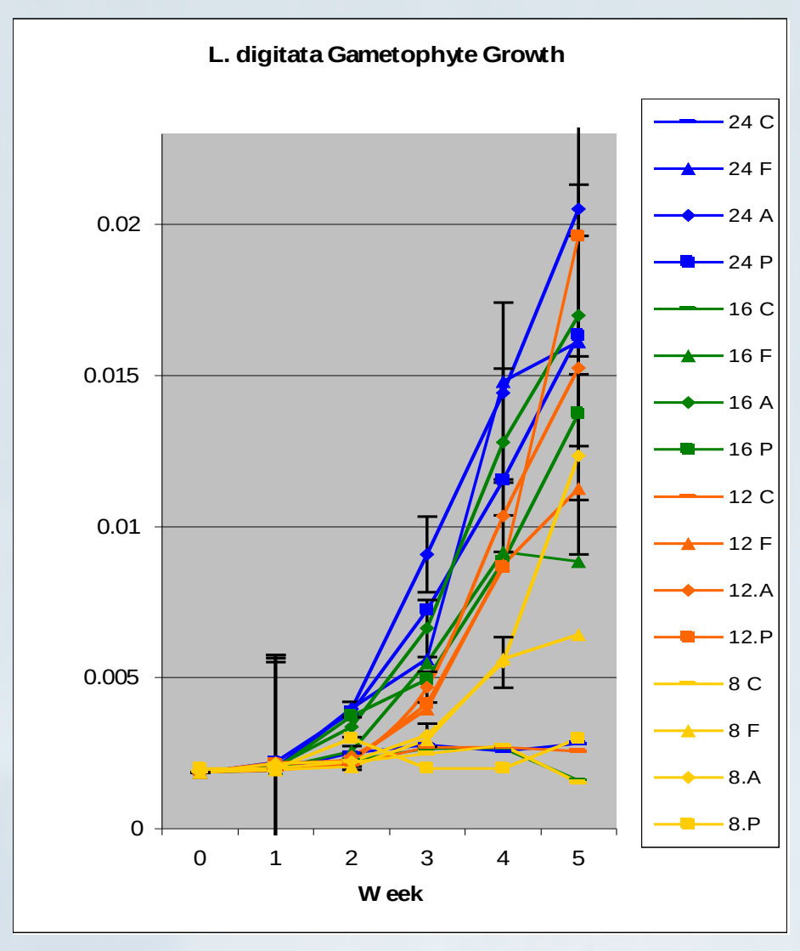
- **4 photoperiods: 8, 12, 16 & 24hr** light source: LP 400 light box, cool white fluorescent adjusted to≈ 10µmol m-2 s-1, red light.
- **3 nutrients and 1 SSW control** 2 commercially available algal culture formulations and 1 commercially available tomato fertiliser.

	NH4	NO3	NO2
Algae1	**4**	**95.5**	**0.5**
Algae2	**15**	**85**	**-**
Fertiliser		**75**	**25**
SSW	**-**	**100**	**-**

- **constant temperature of 10°C±2°C & constant aeration**
- **3 replicates of each nutrient at each light regime = 48 culture flasks**
- **weekly measurements of length** 25 individual gametes/flask, measured along the main growth axis



Results:



The graph above shows the length of the gametophytes over time – the different colours represent the 4 photoperiods and the letters represent each culture medium.

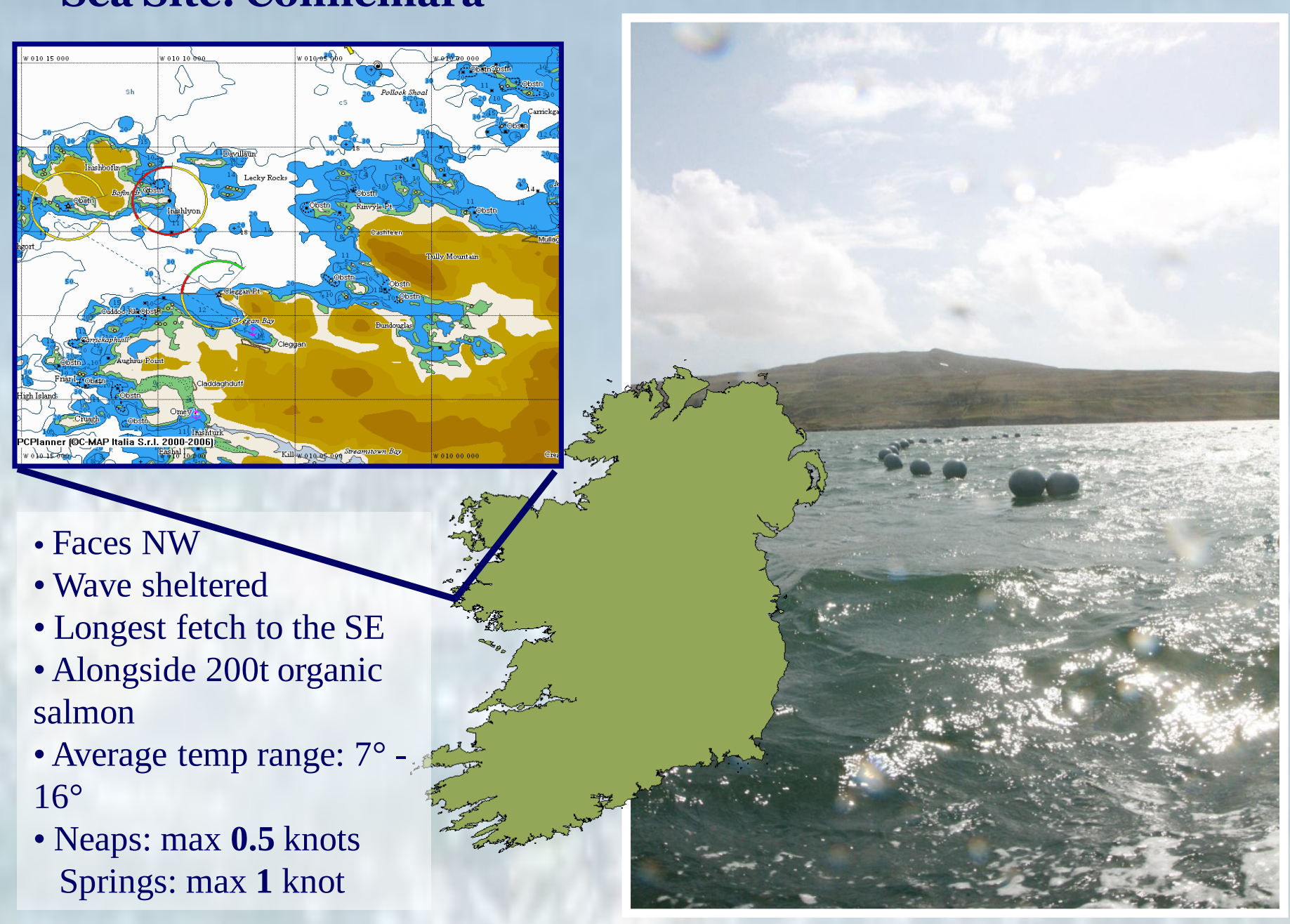
There is considerable variability, and an interaction between culture medium and light regime. A method has been developed to extend the experimental period, which in the example above was limited by length no longer being a good proxy for estimating growth rate. We will repeat this experiment over a longer period with the hope of elucidating the growth patterns more clearly but for example:

- from the graph, growth rate of 24A = **57.13µm.mm.d** and of 8A = **45.06 µm.mm.d**

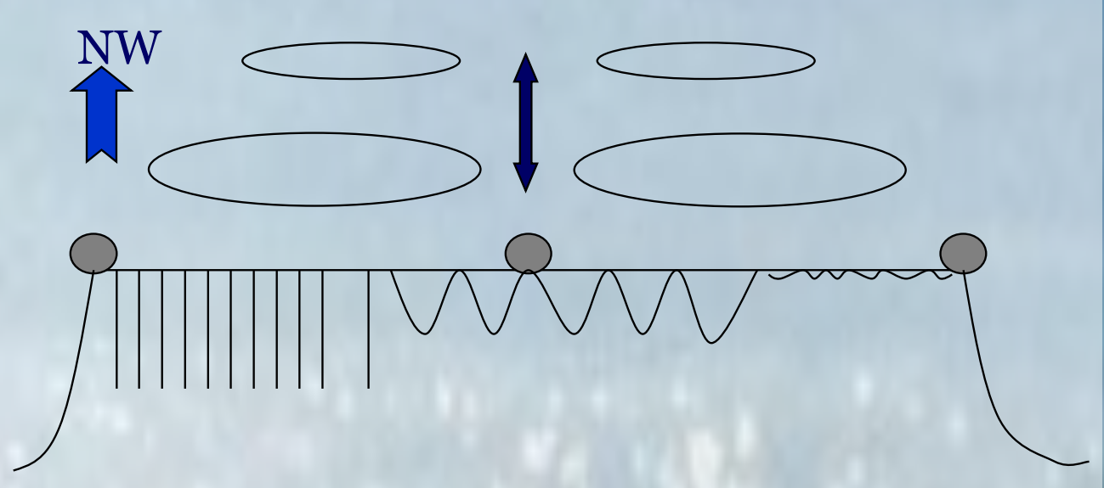
Lab Stage 2: Induction of fertilisation of gametophytes, settlement on culture string and initial growth of sporophytes.

Sea Stage 1: Transfer to sea, on-growing of sporophytes on longlines.

Sea Site: Connemara



- Faces NW
- Wave sheltered
- Longest fetch to the SE
- Alongside 200t organic salmon
- Average temp range: 7° - 16°
- Neaps: max **0.5** knots
  Springs: max **1** knot



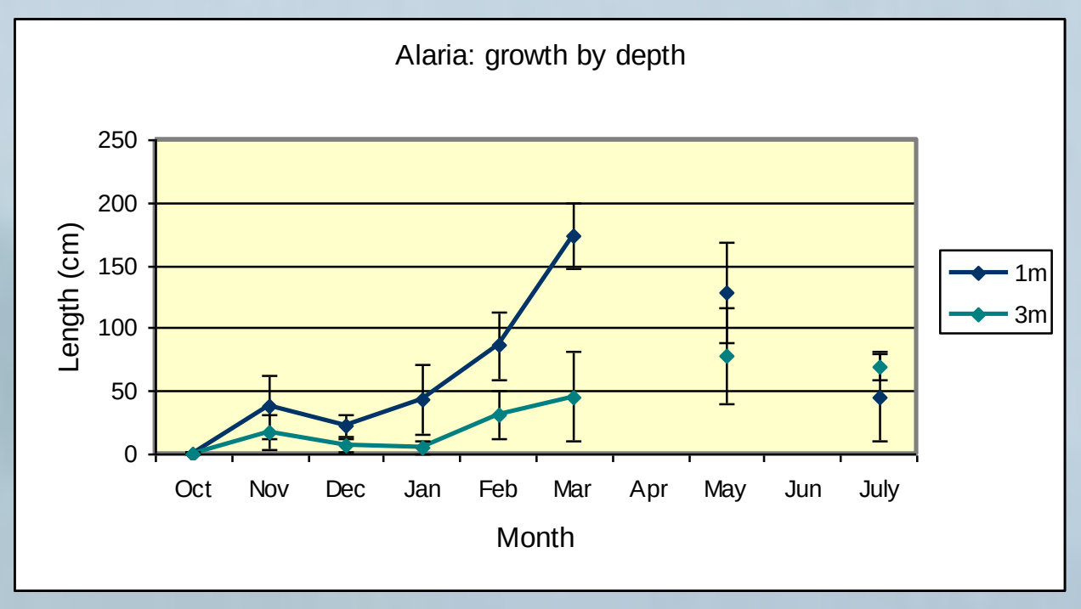
Longline Set-Up: The diagram above shows an example of our longline set-up - perpendicular to the prevailing current (central arrow) and in line with the salmon cages (circles). Various arrangements of attaching the seeded culture rope to the header line were tried - from left: 5m weighted dropper; continual loop; direct onto the header

Factors -
4 species: L. hyperborea, L. digitata, A. esculenta, S. polyschides
2 seeding types: polypropylene vs. kuralon
3 methods of attachment: 5m droppers; continual rope; header
3 months of out-planting: October, December, February
3 depths: 1m, 3m & 5m

Measurements -
Growth – Blade length / width of largest 10 plants / sampling point / month
Biomass – At harvest: total biomass, weight / plant vs. density

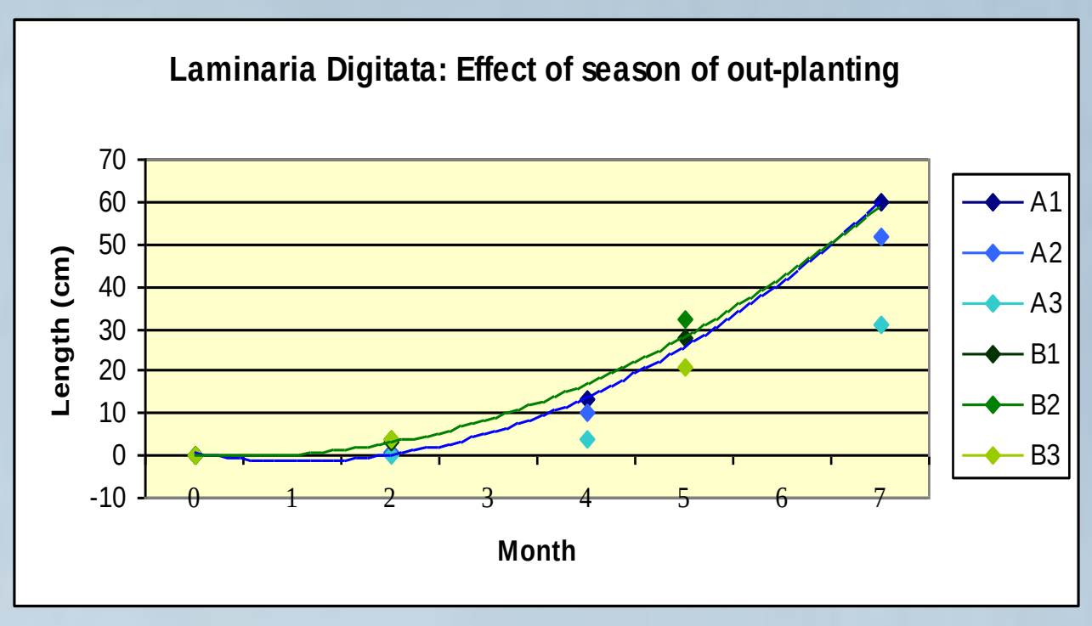
Sea Stage 2: Harvest of mature sporophytes, closing of life-cycle by collection of reproductive material and induction of sporogenesis for new cultures.

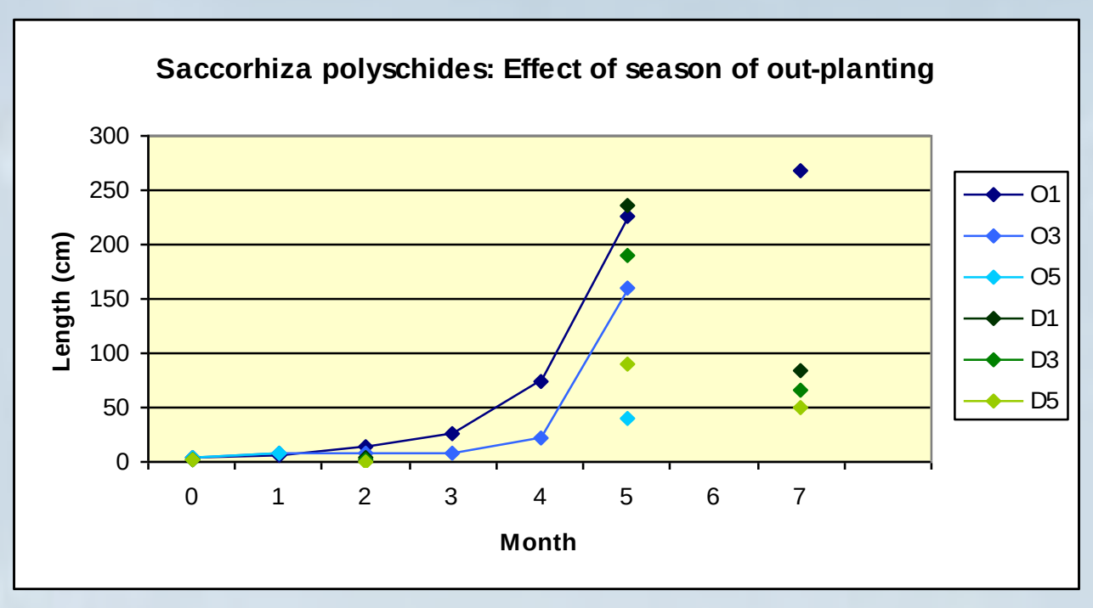
Example Results: Optimisation



Depth: Species' responded differently – For example, *A. esculenta* showed a clear drop in growth rate from 1 to 3m, whereas for *L. digitata* there was little difference in growth rate until 5m depth.

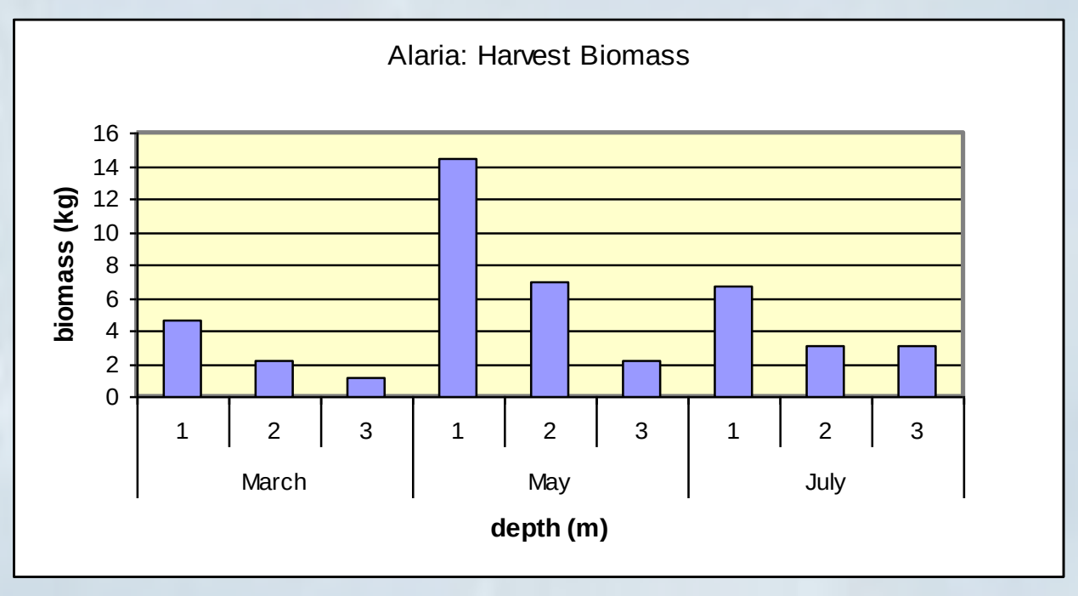
Effect of Depth: Surface water – foreground, 4-5m – background.





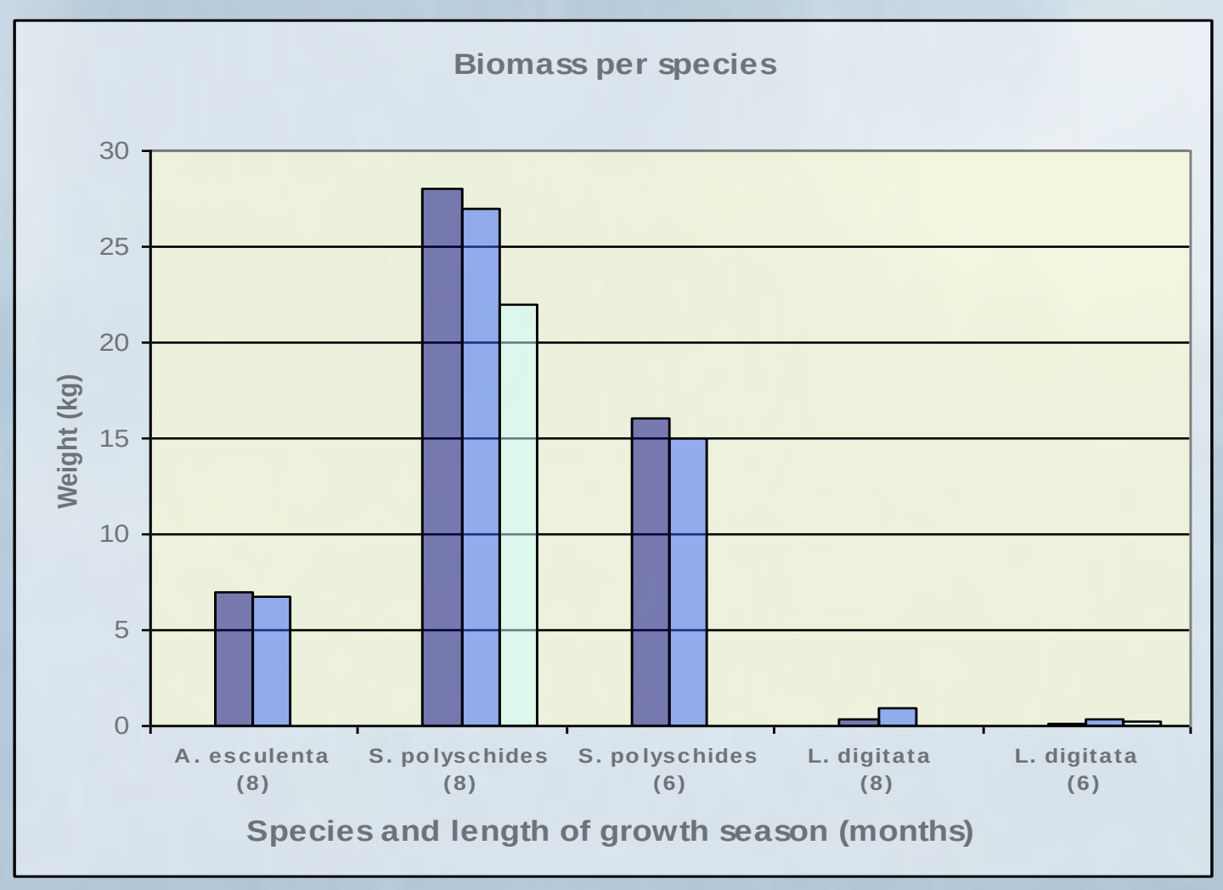
Season: In this case the species' behaved in the same way. The graphs show growth (length by month) according to season of out-planting: blue = early, green = late. The growth curves are similar suggesting that month of out-planting does not affect the rate at which a plant grows. The effect of season of out-planting on biomass (see below) is in lengthening the overall growth period. There is a very defined end to growth at which point plants begin to become heavily epiphytised and attrition of the blades occurs decreasing quality and total biomass.

Season of Harvest: S. polyschides in May (above), and heavily fouled and deteriorated in July (below)



Harvest: This again relates to the length of the growth season and the point at which quality and biomass start to decrease. It is clear that in July this point has been over-reached biomass has been lost.

Results: Biomass



The graph to the left shows the difference in biomass production between species. In this example only the top 30cm of dropper were weighed for comparison. The table below gives total biomass per meter of header line (i.e. per dropper) for each species.

Species	Wet weight per meter header (kg)
Saccorhiza polyschides	55-80
Alaria esculenta	24
Laminaria digitata	2

Extrapolations of yield according to various farm designs: dry tonnes per hectare

	22 - double	33 - single	50 - single	55 - single	Horizontal
Saccorhiza polyschides high	29. 3	22. 1	33. 5	36. 8	**10***
Saccorhiza polyschides low	20. 2	15.2	23	25. 3	**6****
Alaria esculenta	10. 6	7. 9	12	13. 2	**12*****
Laminaria digitata	1. 2	0. 9	1. 4	1. 5	**1. 2*******

S. polyschides high = 80 kgm^{-1}(wet), low = 55 kg m^{-1}(wet) (w:d = 12)
A. esculenta = 24 kg m^{-1}(wet) (w:d = 10)
L. digitata = (w:d = 9)

Droppers:
22 = double (1.5m width) line every 3m
33 = 1 line every 3m
50 = 1 line every 2m
55 = double (1m width) line every 3m

Horizontal looped: 8 x 10m width lanes per hectare
* = 25kg per 50cm section, 30 loops per lane
** = 15kg per 50cm section, 30 loops per lane
*** = 15kg / 50cm section, 50 loops per lane
****1kg / 50cm section, 70 loops per lane

In order to start to estimate potential yields per hectare, the layout of the longlines on a farm-scale needs to be considered. Using the yield data from these experiments the table above shows various estimates (dry tonnes per hectare) according to different farm designs (see box to left for calculations). One of the limitations of such small-scale work is that we do not know how the nutrient regime / hydrodynamics will be affected inside a farm, and hence what sort of overall productivity is likely to be supported. This is clearly shown in the variability of the figures above. However, projected yields are in keeping with other results from the UK and Ireland.

Some Knowledge Gaps:

- How yield will be affected by final longline set-up and farm lay-out, and therefore what realistic potential yields are.
- A measure of the year to year variability in yield.
- What the wider sustainability of large-scale cultivation might be, in terms of: biogenic emissions; sea-floor shading; altered hydrodynamic regimes; as a source of green tides (e.g. Liu et al. 2010); pest and disease outbreaks; and in terms of mitigating eutrophication in inshore waters.

Liu D, Keesing JK, Xing Q, Shi P (2009). World's largest macroalgal bloom caused by expansion of aquaculture in China. Marine Pollution Bulletin 58: 888-895.

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