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Memo

KELPPRO WP1: Industrial kelp cultivation scenarios (V0.1)

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Introduction and background

According to the KELPPRO proposal the main objectives of WP 1 are to

- Identify key environmental variables for efficient kelp production;
- Identify suitable kelp production locations and potential conflicts with natural populations;
- Estimate future industrial cultivation scenarios ranging in volume from ”probable” to ”extreme”.

While the main deliverable of this WP will be a “paper on the potential for kelp cultivation along the Norwegian coast based on region and natural physio-chemical conditions”, a deliverable that is perhaps more important for the KELPPRO project is the present “report including specification of large scale cultivation scenarios for WPs 2 and 3 and recommendations for WP 5”; see Objective 3 below. The report is written in the style of an informal memo. Most of the material will go into the paper in one form or another, reinforced with more citations.

Objective 1: Key environmental variables for efficient kelp production

It is not within the scope of WP 1 to perform an exhaustive scientific field survey in order to rank the importance of (all?) various environmental variables for the growth and productivity of kelps; this would be an impossibility, one can only prove positives. An obvious remark is this: Because the focus of KELPPRO is mainly on *cultivated kelp* it is not necessary to consider all factors necessary to complete a full life cycle for kelps. The existence of a suitable substrate must be taken for granted (and we will not discuss any details regarding cultivation technology here).

The purpose of identifying the main variables is to be able to say something about the kelp production potential in various locations along the Norwegian coast, or at least be able to compare the production potential in these locations: given knowledge about the environmental variables we deduce growth responses. We are therefore only interested in considering variables for which some sort of quantitative

Table 1: Key variables important for kelp growth and production

Variable	Remarks, references
Temperature	[3]1
Light intensity (PAR)	This is also connectd to the concentration of organic (plankton, detritus, DOM) and inorganic matter (silts) in the water
Latitude	Important for sun angle and total irradiance, but also important for (changes in) day length and potential photoperiodic effects, though empirical proof is somewhat lacking [6]
Nitrate (NO_3^-) concentration	
Ammonium (NH_4^+) concentration	Including, possibly, NH_3^+.
Phosphate (PO_{43}^-) concentration	In the natural ecosystem nitrogen (nitrate) is considered limiting.
Micronutrients and trace elements	Iodine, iron, magnesium
Current velocity	
Wave exposure	Leading to wave-induced turbulence and reduction of the diffusion boundary layer
Epiphyte infestation	E.g. bryozoans, hydroids. Including in this context also parasites like snails etc. It is not clear if we will include epiphytes in KELPPRO, but there will be an effort in MACROSEA at some point.
CO_2 concentration	

information is available. A previous effort to use data on kelp growth responses to some environmental factors in a "siting exercise" is presented in [7]. The chapters in [15] give a hint as to the perception of the importance of some variables in the seaweeed research community.

The variables may interact directly or indirectly, e.g., temperature interacts directly with the algae, but may also indirectly interact by modifying phytoplankton concentration and hence light and nutrient concentrations.

In terms of potential cultivation areas and production potential, anthropogenic variables may play a rôle, too. The focus here is on cultivation, not (necessarily at least) natural population. In [6] four variables (N (DIN), light, temperature, currents) have been used, but this selection perhaps reflects which variables one might hope to get some detailed (time and space) information about more than what is actually important.

Objective 2: Suitable production locations and potential conflicts with natural populations

The evaluation of suitable production locations has been made using the coupled physical-biological-kelp model system SINMOD (`www.sintef.no/sinmod`, [4]). Model domains of 800 m horizontal resolution have been used (Fig. 1). So far simualtions have been run for the entire Norwegian coast, except Finnmark. For Central Norway (the middle red rectangle in Fig. 1) simulatons have been run for the years 2012-2016. For Southern Norway, a simulation for the period from January 1 to August 30, 2013, has been run. For Nordland and Troms (Northern Norway except Finnmark) a simulation for the period from February 3 to September 19, 2014, has been run. More, and longer, simulations will be run as a basis for the journal publication on the kelp production potential. The procedure for setting up, running, nesting and forcing the simulations is presented in e.g. [4]. The best description of the food web structure of SINMOD is still

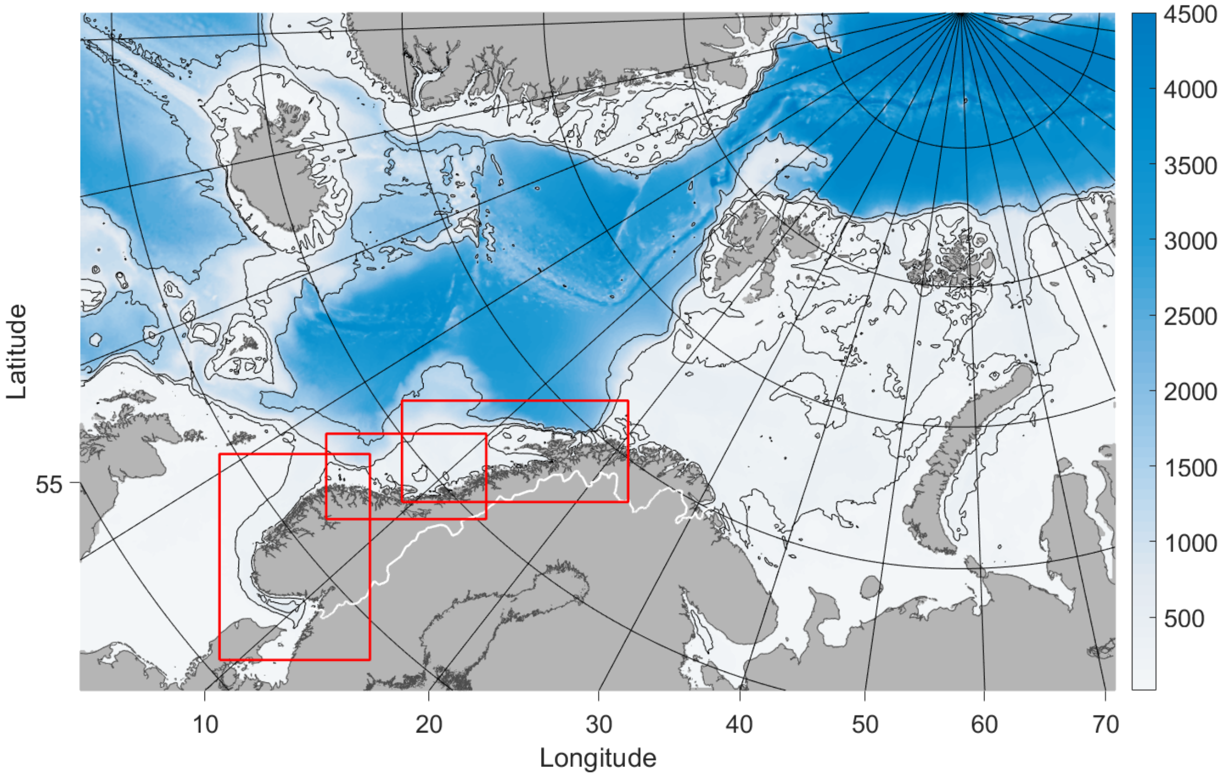

Figure 1: Large scale model domain of 4 km horizontal resolution including the countours, in red, of the 800 m resolution model domains for the Norwegian coast. The colours indicate bottom depth, while the black curves are 200, 500, and 1500 m isobaths. The coast of Finnmark is also covered in 800 m resolution, but so far the simulation has not been run. This 4 km model domain is nested from a larger model domain of 20 km resolution.

[14].

The simulations were initialized with the same kelp state variable values in all model grid cells as follows:

- initial frond area: $A_0 = 0.2\,\mathrm{cm}^2$;
- initial nitrogen reserve: $N_0 = 0.02$ (corresponding to a nitrogen content of 1.8% of the dry weight);
- initial carbon reserve: $C_0 = 0.4$ (corresponding to a carbon content of 32% of the dry weight).

It is the dry weight that has been used as a basis for evaluating the production potential. The biomass of individuals is calculated from the three states - frond area A, nitrogen reserve level N, carbon reserve level C - according to [6]. In this **preliminary** version we consider only one cultivation season from the beginning of February to the beginning of June. Depending on the location, epiphyte fouling may lead to significant, or eve loss of biomass. Hence we assume harvest in June.

An index for the kelp cultivation potential in Norway\Finnmark is presented in Figure .

It is interesting to compare the results presented where with other published results on production (Table 2). There are very few good data on the *large scale* cultivation potential for seaweed. The results from China [17] are particularly interesting. The total Chinese production area covers approximately 400 km^2, with a total production of perhaps 6500000 t (wet weight). Of course, this is not a single, connected, production zone, so in particular those figures cannot be used directly to determine carrying capacity.

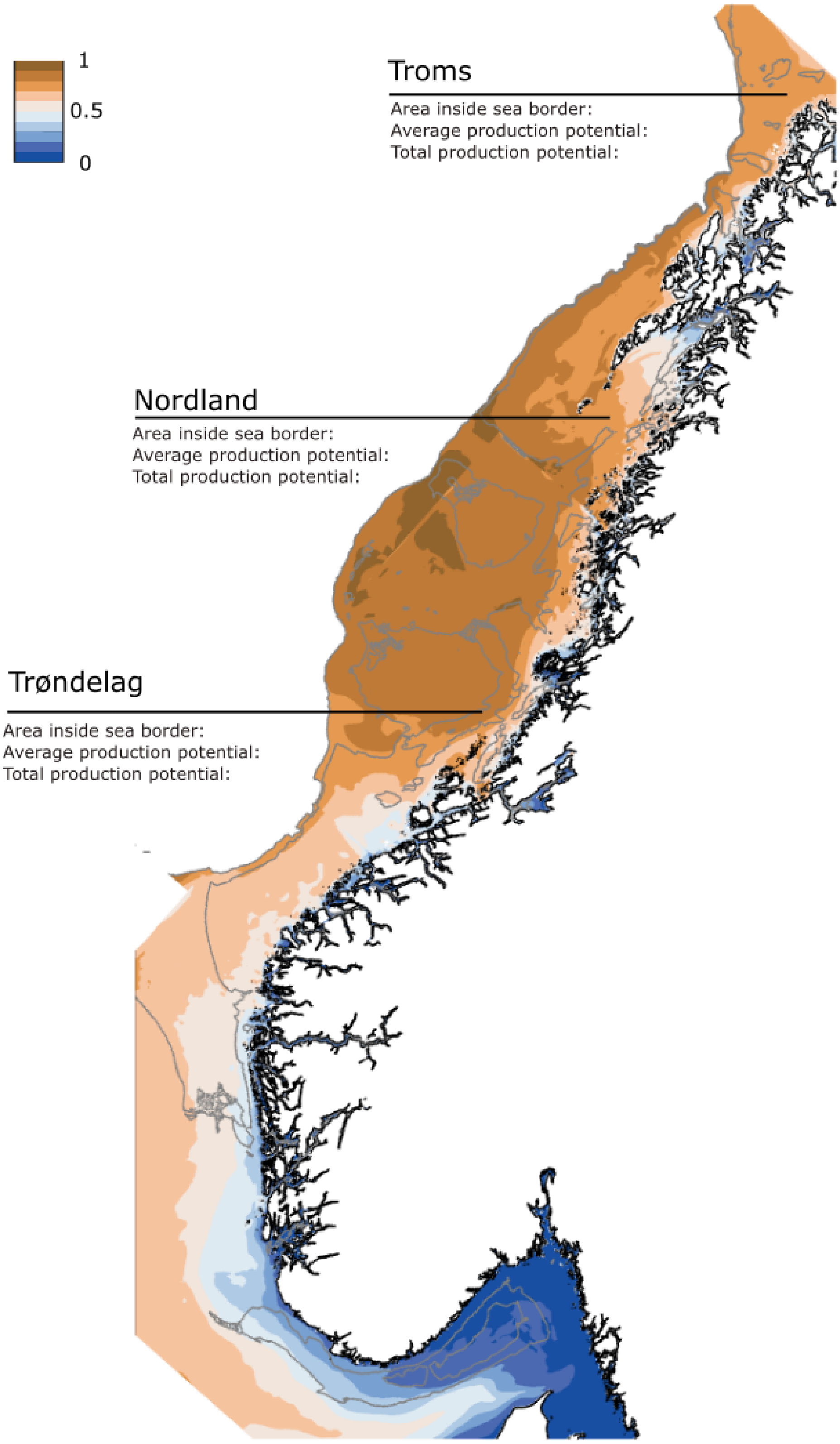
1
0.5
0
Troms
Area inside sea border:
Average production potential:
Total production potential:
Nordland
Area inside sea border:
Average production potential:
Total production potential:
Trøndelag
Area inside sea border:
Average production potential:
Total production potential:

Figure 2: L.

Table 2: Estimert dyrkingspotensial for noen makroalger. Alle tallene er oppgitt som tonn våtvekt per hektar, og er eventuelt regnet om til denne enheten fra de oppgitte referansene.

Art	Biomasse ($\mathrm{t\,ha^{-1}}$)	Referanser og kommentarer
Saccharina japonica	32	[16], gjennomsnitt for Sanggou-bukten i Kina. Omregnet fra tørrvekt biomasse med antatt tørrstoffinnhold på 15 % (vår antagelse)
Saccharina japonica	162	[17], total kinesisk produksjon fordelt på totalt kinesisk dyrkingsareal. Omregnet fra tørrvekt biomasse med antatt tørrstoffinnhold på 15 % (vår antagelse)
Saccharina latissima	220	[13], oppskalering basert på småskala forsøk
Palmaria palmata	180	[13], oppskalering basert på småskala forsøk
Saccharina latissima	22,5–27,6	[10], oppskalering fra dyrking på mindre areal
Saccharina latissima, tare	200	[8], oppskalering
Laminaria hyperborea	90–270	[2] sitert og omregnet i [12] til en årlig biomasseproduksjon på 9–27 $\mathrm{kgm^{-2}}$. Fra Møre og Romsdal.
Saccharina latissima	95	[11], omregnet fra dyrket biomasse på 19,95 tonn per 0,21 hektar.
Alaria esculenta	63	[11], omregnet fra dyrket biomasse på 13,3 tonn per 0,21 hektar.
Saccharina latissima	32–220	[5], gjennomsnittsverdier basert på modellresultater for Møre og Romsdal. Direkte sammenlignbart med denne rapporten. Ulike områder og utsettidspunkt.
Saccharina latissima	45–91	Simulert, denne rapporten. Gjennomsnitt for områdene innenfor grunnlinjen i Trøndelag, 2012-2016.
Saccharina latissima	92–164	Simulert, denne rapporten. Gjennomsnitt for områdene utenfor grunnlinjen i Trøndelag og på kontinentalsokkelen (bunnyp mindre enn 500 m). Perioden 2012-2016.

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Verification of simualtion results

A memo on comparison of SINMOD simulation results with cultivation data and field data on natural kelp populations has been written up in Norwegian previously (august 2, 2017). Results from this model verification exercise will be included in the paper, and we will not go into the details here.

Objective 3: Future industrial cultivation scenarios

While the Norwegian seaweed aquaculture production in 2016 weighed in at less than 100 t [1], it has been suggested that the production in 2050 may be as high as 2×10^7 t with a turnover of 4×10^{10} NOK per year [9]. Here, we consider four main/national/large scale scenarios:

A. Total produciton: 10 000 t. Total production area: 1000 ha (Extensive and non-intensive production)

B. Total production: 10 000 t. Total production area: 100 ha (Intensive and non-extensive)

C. Total prodution: 20 000 000 t. Total production area: 200 000 ha (Extensive and non-intensive production)

D. Total production: 20 000 000 t. Total production area: 20 000 ha (Extensive and intensive production)

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