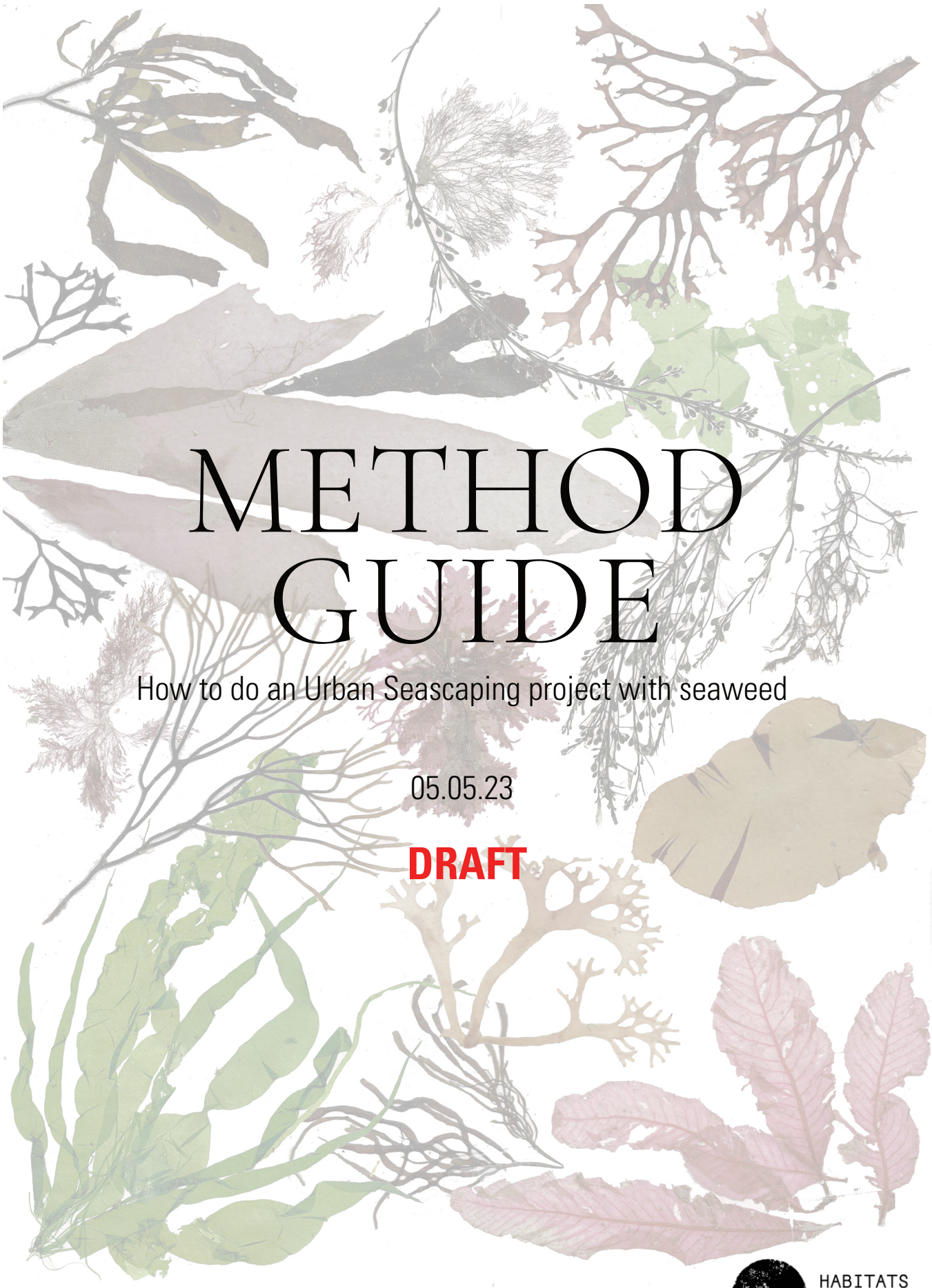


METHOD GUIDE

How to do an Urban Seascaping project with seaweed

05.05.23

DRAFT

HABITATS
SKAB PLADS
TIL NATUREN

Contents

INTRODUCTION: Main steps to engage with seaweed in urban contexts

Introduktion - Vigtigste trin til at engagement med tang i bykontekster

The process behind working with marine life forms such as seaweed is different from working with terrestrial plants. Therefore, this is a methodology guide as to how one could approach working with seaweed particularly in an urban context, with all the different environmental factors that needs to be considered in order to ensure the best outcome.

Therefore, the purpose of this guide is to outline the main broad steps for working with seaweed however, it is not a linear step-by-step process as these different steps will be much more intertwined, going back and forth between different steps.

Moreover, the guide is written with the intention of bringing in different experts (at different times and stages of a project) as engaging with the marine realm is a complex endeavour that requires inter-disciplinary collaboration and involvment of different stakeholders.

As context specific information is critical information to work with, it is encouraged to search for documents and maps that may have dealt with the specific site in question already, providing more detailed and in-depth information by other researchers and companies. Google Scholar and general internet search should always be conducted for potential further information and scientific articles (and books) can be found on the following websites:

Educational Institution's online library search (membership/login details required):

- Aalborg University: https://www.en.aub.aau.dk/
- Aarhus University: https://library.au.dk/
- Aarhus Architecture School: https://aarch.dk/en/find-materialer/
- Copenhagen University: https://kub.ku.dk/english/searchandfind/
- Danish Technical University: https://www.bibliotek.dtu.dk/en/
- Royal Danish Academy: https://kbdk-kadk.primo.exlibrisgroup.com/discovery/jsearch?vid=45KBDK_KADK:KADK
- Southern University of Denmark: https://www.sdu.dk/en/bibliotek

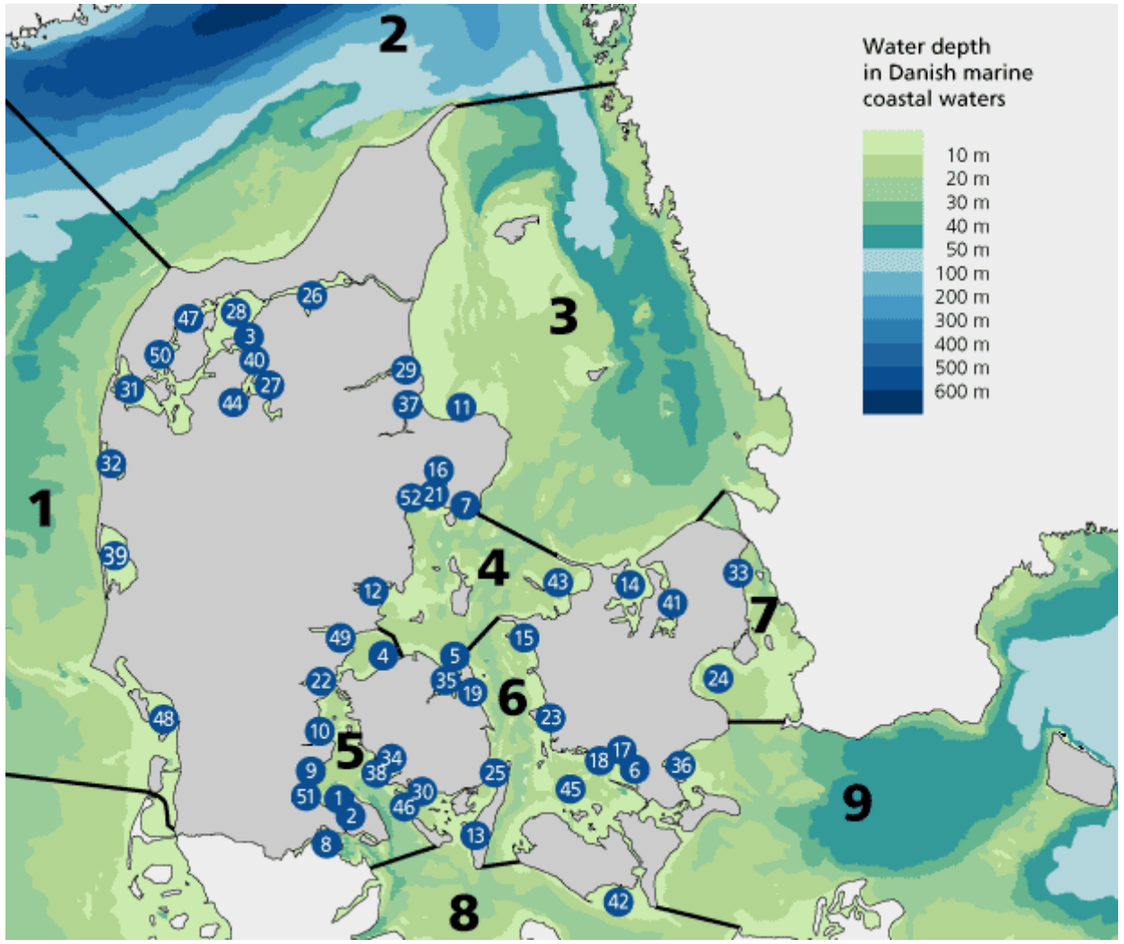
- And the national Danish library: https://www.kb.dk/en/find-materials

QGIS portal for maps (for Denmark):

- Miljø QGIS: https://mst.dk/service/miljoegis/

The next following section will discuss in detail the main 6 steps required for working with seaweed in Denmark.

Note: Read this report in conjunction with the SEAWEED CATALOGUE



Danish marine sub areas		Estuaries and coastal waters					
1	North Sea	1	Als Sund	19	Kertinge Nor	37	Randers Fjord
2	Skagerrak	2	Augustenborg Fjord	20	Kieler Bugt	38	Ringgård Bassin
3	Kattegat	3	Bjørnsholm Bugt	21	Knebel Vig	39	Ringkøbing Fjord
4	Northern Belt Sea	4	Båring Vig	22	Kolding Fjord	40	Risgårde Bredning
5	Little Belt	5	Dalby Bugt	23	Korsør Nor	41	Roskilde Fjord
6	Great Belt	6	Dybsø Fjord	24	Køge Bugt	42	Rødsand
7	The Sound	7	Ebeltoft Vig	25	Langelandssund	43	Sejerø Bugt
8	Southern Belt Sea	8	Flensborg Fjord	26	Limfjorden	44	Skive Fjord
9	Baltic Sea	9	Genner Fjord	27	Lovns Bredning	45	Smålandsfarvandet
		10	Haderslev Fjord	28	Løgstør Bredning	46	Sydfynske Øhav
	The Belt Sea	11	Hevring Bugt	29	Mariager Fjord	47	Thisted Bredning
	4, 5, 6, 8	12	Horsens Fjord	30	Nakkebølle Fjord	48	Vadehavet
		13	Hovvig	31	Nissum Bredning	49	Vejle Fjord
		14	Isefjord	32	Nissum Fjord	50	Visby Bredning
		15	Kalundborg Fjord	33	Nivå bugt	51	Åbenrå Fjord
		16	Kalø Vig	34	Nørrefjord	52	Århus Bugt
		17	Karrebæk Fjord	35	Odense Fjord		
		18	Karrebæksminde bugt	36	Præstø Fjord		

Figure 1. Map of the Danish waters by the Danish Environmental Protection Agency & National Environmental Research Institute
https://www2.dmu.dk/1_viden/2_miljoe-tilstand/3_vand/4_eutrophication/map.htm

STEP I. Check the presence (data) of seaweed in a particular area in Denmark

Tjek tilstedeværelsen (data) af tang på et bestemt område i Danmark

It is important to first understand whether there is any presence of marine life in the area of interest. A quick way to check is to go to: marine-vegetation.satlas.dk/ (based on aerial mapping) to see if there is any sign of marine vegetation (could be eelgrass and/or seaweed).

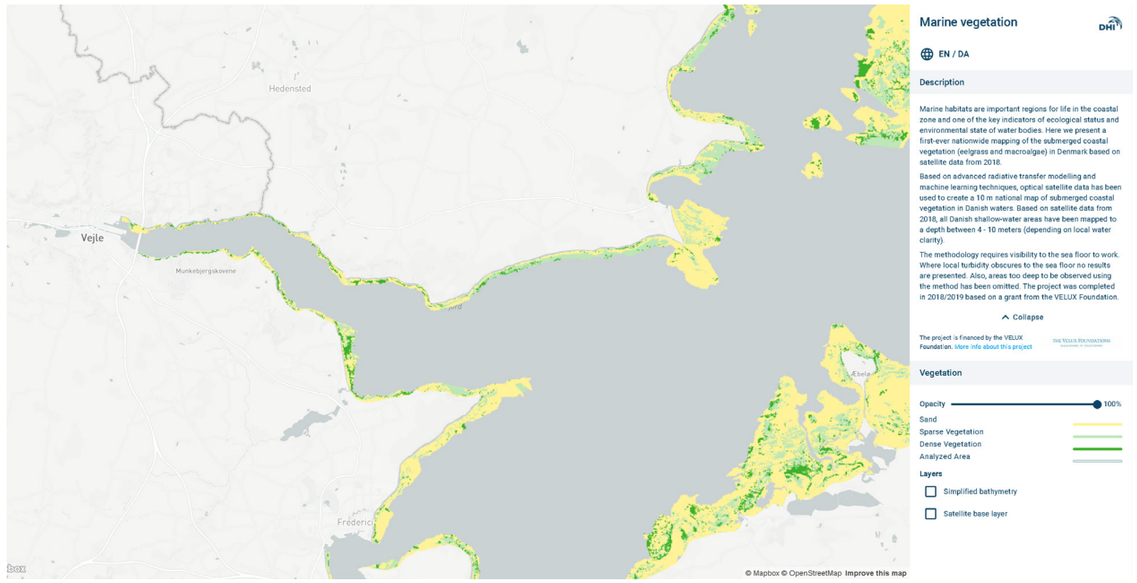


Figure 2. Marine Vegetation Atlas for Vejle, Denmark. Yellow indicates sand, and green indiates presence of marine vegetation such as eelgrass or seaweed.

Consult the book from Ruth Nielsen and Steen Lundsteen on "Danmarks Havalger" (2019) and naturbasen.dk/ to see the potential sightngs of various macroalgae that could be present in the area of interest. Check if there are more detailed data on a particular site on research search engines (i.e. university library search, Google Scholar etc.).

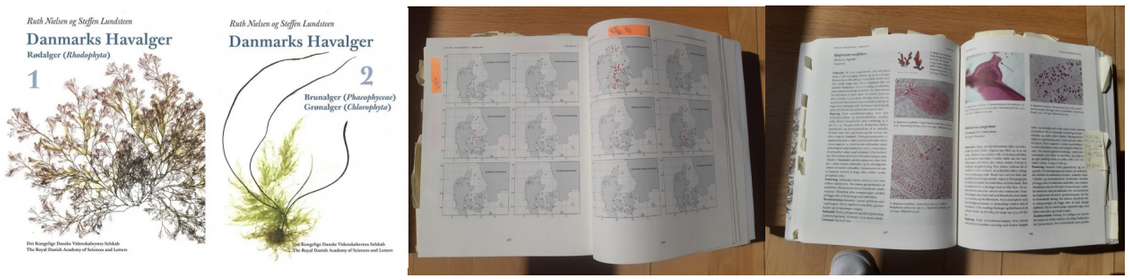
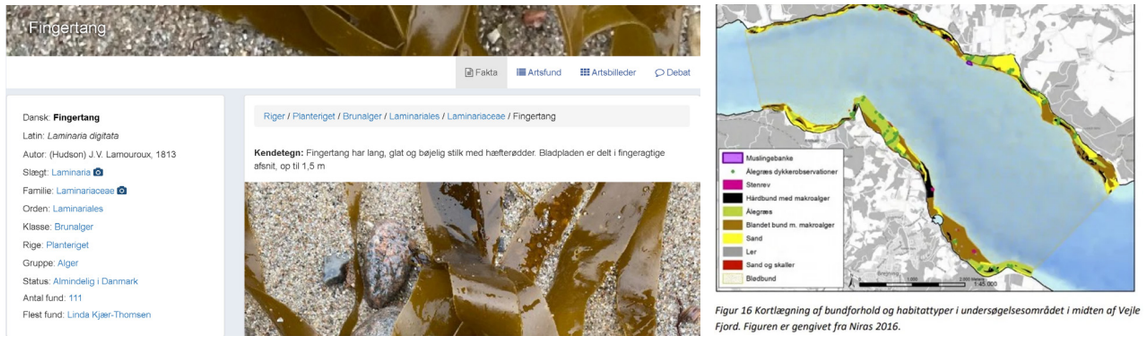


Figure 3. Danmarks Havalger books (2019) showcase the approximate location of where the different types of seaweed species live.



Figur 16 Kortlægning af bundforhold og habitattyper i undersøgelsesområdet i midten af Vejle Fjord. Figuren er gengivet fra Niras 2016.

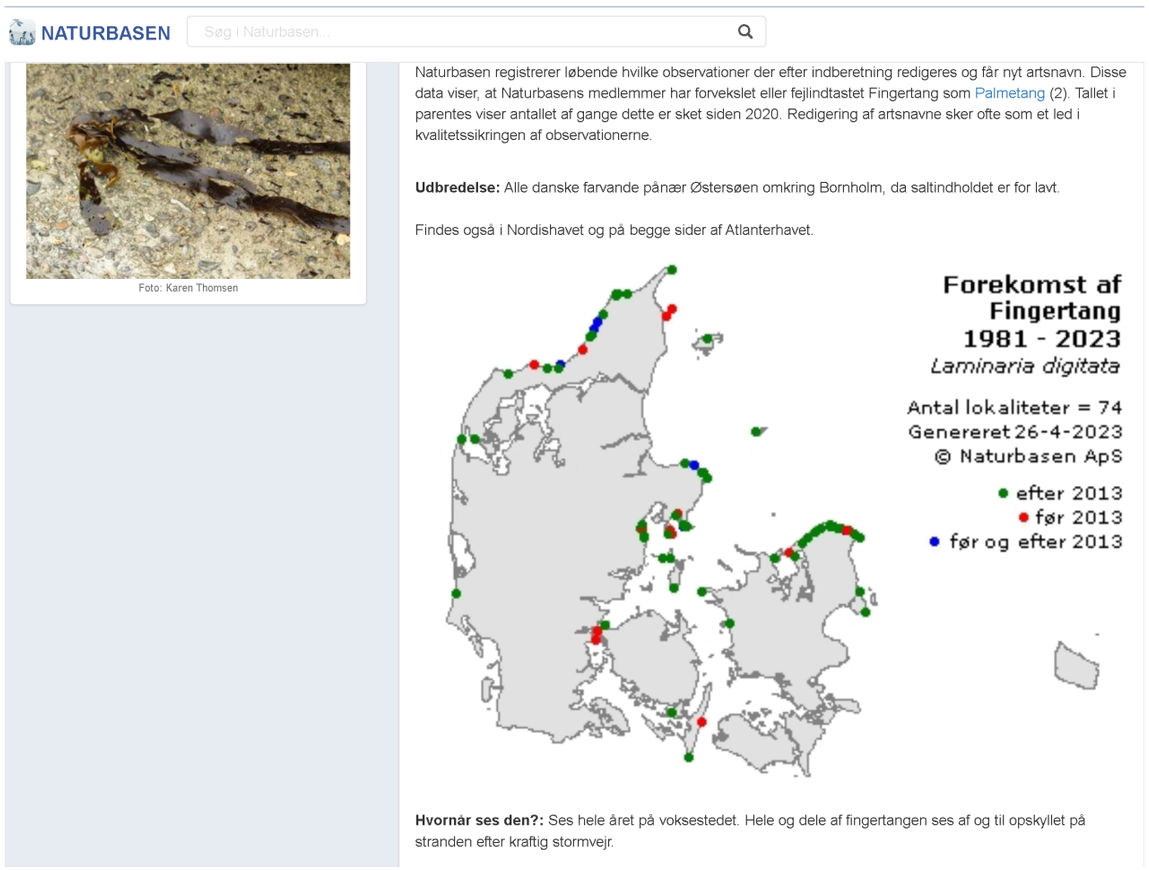


Figure 4. Naturbasen.dk - an online data base for various plants in Denmark (both terrestrial and marine)

REFERENCE

1. https://marine-vegetation.satlas.dk/
2. Lundsteen, S. and Nielsen, R., 2019. Danmarks Havalger. Scientia Danica, Biologica. Copenhagen: Det Kongelige Danske Videnskabernes elskab.
3. http://www.naturbasen.dk/

STEP II. Investigate the physical conditions of seaweed

Undersøg de fysiske forhold for tang

There are many locally specific contextual and environmental factors that need to be considered in order to purposely grow/introduce seaweed in the particular area of interest. Some of the important factors that one needs to consider are:

1. **Water clarity (nutrient load)**
   - This will help determine whether it will be difficult to grow seaweed (or eelgrass) in a particular area. If the site has poor water clarity due to nutrient load (from surrounding agricultural activities) then, a test site needs to be made to see if seaweed could grow in these waters and whether it will survive the summer and winter months.

2. **Salinity and temperature level**
   - Certain seaweed (i.e. kelp species) requires saltier waters in order for them to grow. Therefore, growing kelp species for wave attenuation and food cultivation may require areas in the deeper, saltier and colder waters.

3. **Tidal variance (hydrology)**
   - Not all types of seaweed can withstand long periods of being exposed dry conditions, therefore, it is important to know that any interventions are in waters that will be inundated. Seaweed also requires good circulation/movement of water as they depend on the supply of nutrients for survival.

4. **Sea bed conditions**
   - Seaweed grows either by anchoring itself on hard surfaces like rocks or they float around absorbing nutrients in the water. Muddy areas do not provide a hard substrate for seaweed to attach on to, and can make the water clarity cloudy, making it difficult for seaweed to have access to sunlight for photosynthesis.

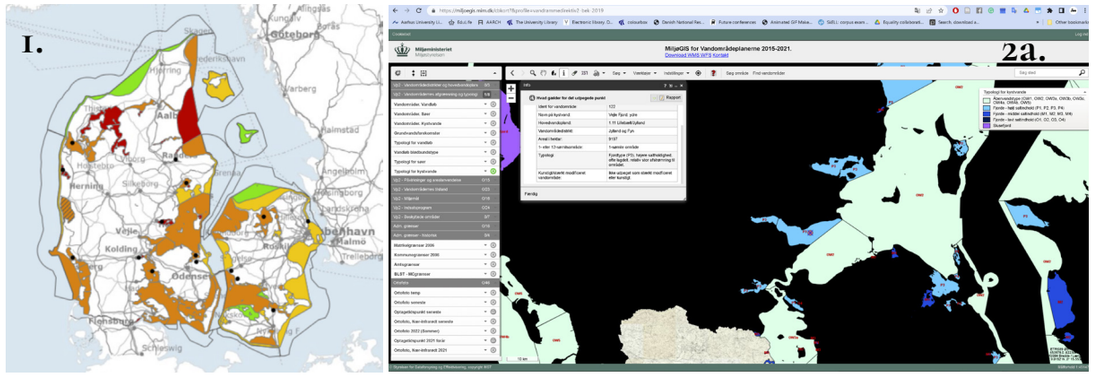


Figure 5. (Left) Map of the various ecological conditions of Danish coastal water quality. (Right) Map of the different salinity level of Danish coastal waters.

REFERENCE

1. https://miljoegis.mim.dk/spatialmap?profile=vandrammedirektiv3tilstand2021
2a. https://miljoegis.mim.dk/cbkort?&profile=vandrammedirektiv2-bek-2019

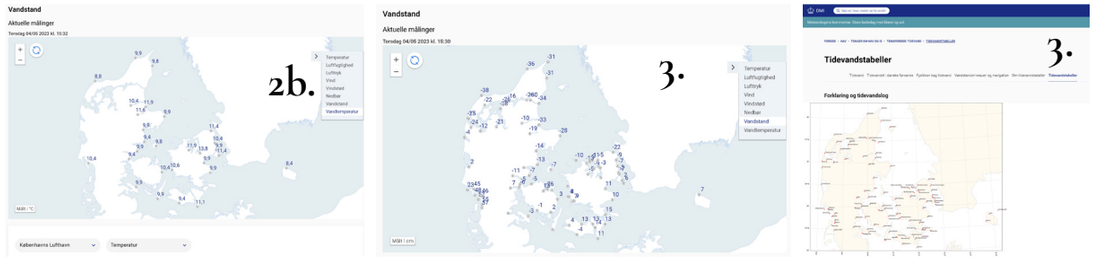


Figure 6. (Left) Map of the various Danish coastal water temperatures from DMI. (Middle & Right) Map of the various tidal variations from various monitoring centers across Denmark from DMI.

REFERENCE

2b. https://www.dmi.dk/vandstand/
3. https://www.dmi.dk/hav-og-is/temaforside-tidevand/tidevandstabeller/ and https://www.dmi.dk/vandstand/

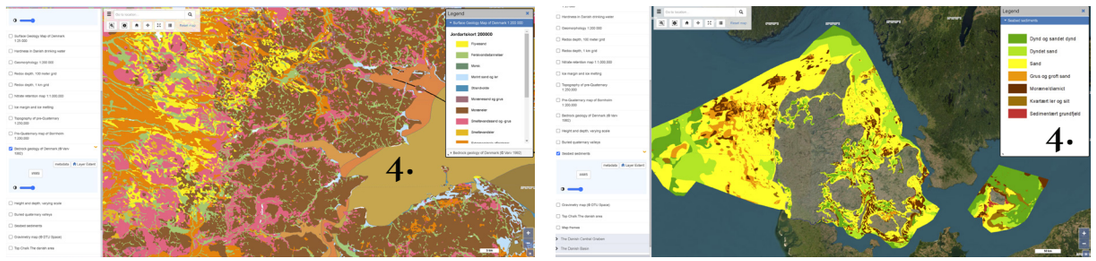


Figure 7. Maps of the various soil and sea bed substrate conditions in Denmark.

REFERENCE

4. https://data.geus.dk/geusmap/?mapname=denmark&lang=en#baslay=baseMapEsriImagery&optlay=optLayHillshadeDa&extent=-111612.79883733392,5754710.314980582,1444978.1110849339,6491658.823896906

5. **Bathymetric data**
- Different types of seaweed grow in different depth (due to various factors such as, temperature, light levels, salinity etc.), therefore, bathymetric data is an important design parameter for growing seaweed. You can purchase a Søkort from https://www.kobsokort.dk/categorynav.aspx?catid=917 and refer to: https://gst.dk/soekort for more detailed bathymetric data.

6. **Local historical documents**
- It is important to understand what used to grow in a particular area of interest, as it will indicate an appropriate environmental condition for a particular seaweed to grow. There are data in aerial maps and photographs from the past and talking to the local fishermen who have knowledge of what used to grow in these areas.

7. **Protected areas, various marine zones and coastal types**
- Check if the area of interest is a nature protected zone (i.e. Natura2000's marine protected areas) and the type of coastal habitats and animals exist in these areas.

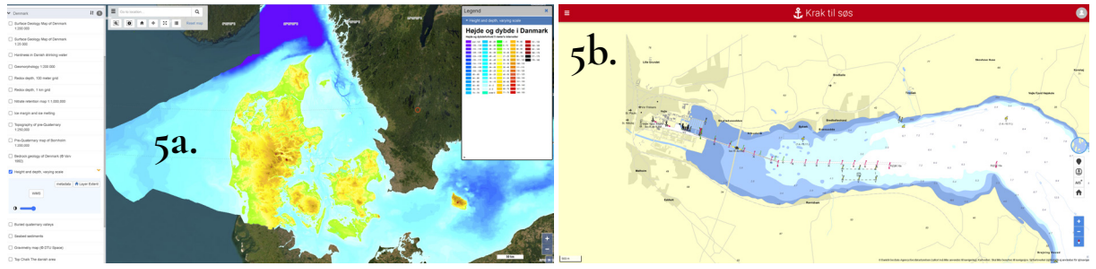


Figure 8. Maps of the topobathy (topography + bathymetry) of Denmark

REFERENCE

5a. https://data.geus.dk/geusmap/?mapname=denmark&lang=en#baslay=baseMapEsrilmagery&optlay=optLayHillshadeDa&extent=-111612.79883733392,5754710.314980582,1444978.1110849339,6491658.823896906

5b. https://tilsos.krak.dk/

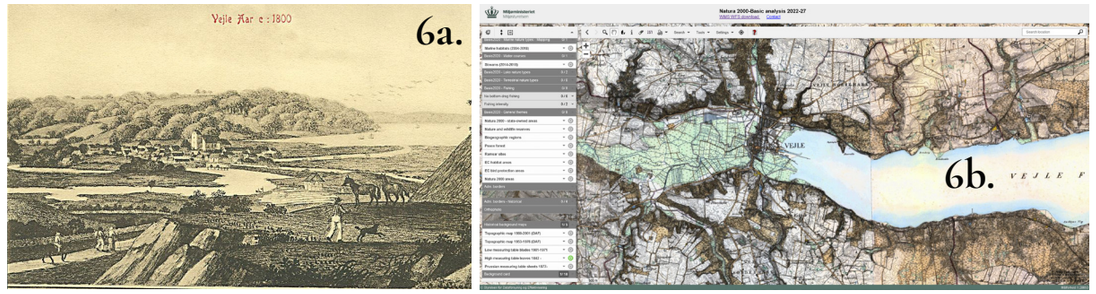


Figure 9. (Left) Drawings, paintings (i.e. Golden Age period) and other depictions of the coastal cities to understand what used to exist in the coast lines before rapid urbanisation (i.e. before the Industrial Revolution of the late 19th century). (Right) Map of the late 19th century plans of various Danish coastal cities - usually showcasing the amount of green spaces (i.e. bogs, wetlands, marshes and meadows) that used to exist before the rapid urbanisation from the industrial revolution.

REFERENCE

6a. Historical search on the old (19th century) images, paintings and drawings on Danish coastal cities

6b. https://miljoegis.mim.dk/spatialmap?profile=natura2000planer3basis2020 and https://www.kb.dk/find-materiale/tjenester/danmark-set-fra-luften

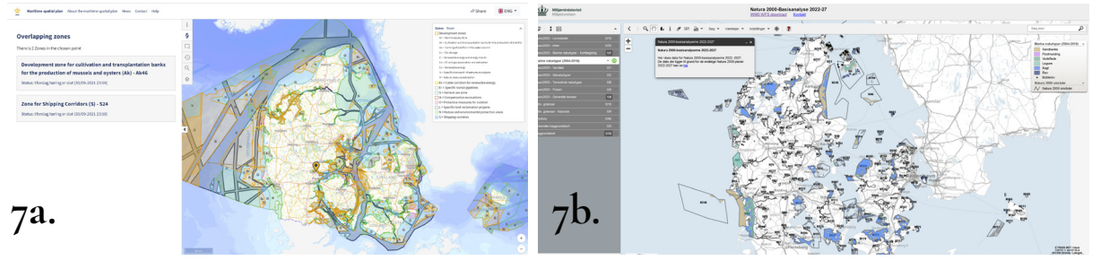


Figure 10. (Left) Map of all the different marine zones in Denmark (with different uses and permissions). (Right) Map of all the (marine) nature protected areas (MPA - Marine Protected Zone, such as Natura2000, Ramsar sites etc.) and the different coastal habitats in Denmark.

REFERENCE

7a. https://havplan.dk/

7b. https://miljoegis.mim.dk/spatialmap?profile=natura2000planer3basis2020

STEP III. On-site sampling & testing

Prøveudtagning på stedet

There is a need to confirm on-site the initial broad search from step 1 of the presence of seaweed on a particular area of interest. There are several ways to gather data/evidence of seaweed's presence.

1. Scuba diving, underwater imaging (GoPro) and videos to gather data of life below the water
2. Aerial drone photos[2], site photos
3. Shallow water coastal observation

4. There may also be a need to do a test plot on a smaller scale[1] for a year on challenging areas/site with bad ecological conditions of the water (i.e. can seaweed survive the winter? If it can, it is a good indication to expand it to a larger scale/upscale installation[3])

Figure 11. Site observations in Vejle looking for the presence of seaweed in the near vicinity. Image credit: Vejle Municipality, Niels Rysz and Soo Ryu

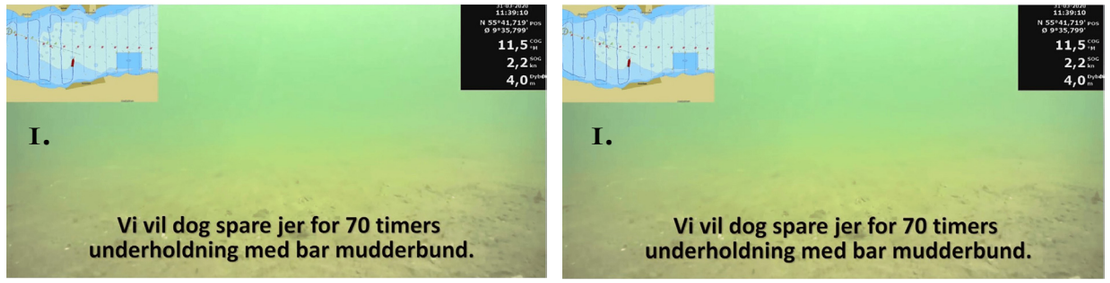


Figure 12. Screenshots from the 70hr of underwater footage of Vejle Fjord - largely a dead marine zone. Image credit: Sund Vejle Fjord.

Figure 13. Aerial images of the shallow coastal waters in the outer Vejle fjord showing signs of marine vegetation such as seaweed and eelgrass. Image credit: Sund Vejle Fjord.

Figure 14. Images of eelgrass testing in Vejle Fjord and signs of seaweed growing on stone reef installed on July 2022 and photo taken on November 2022. Image credit: Sund Vejle Fjord.

FOOTNOTE

1. Based on a semi structured interview with Mads Fjeldsø Christensen from Vejle Municipality on the 25/04/23.
2. Aerial photos of Denmark from 1950's to now can be seen on: https://www.kb.dk/find-materiale/tjenester/danmark-set-fra-luften
3. The duration of the testing period is dependent on the specific site conditions and can be driven by budget constraints.

STEP IV. Consult with a local (marine) expert

Rådfør dig med en (lokal) havekspert

Here are some of the main experts working with seaweed for various purposes in Denmark. Because seaweed (or other marine life forms) are highly dependent on the local conditions, it is really important to consult with the local marine biologists (where possible) about the likelihood of survival of these seaweeds and what kind of conditions are needed for a nature-based solutions to work.

Seaweed researchers
- 1- Dorte Krause-Jensen
- 2- Annette Bruhn
- 3- Teis Boderskov
- 4- Ruth Nielsen & Steffen Lundsteen

Seaweed as food
- 5- Ole Mouritsen
- 6- Marianne Thomsen
- 7- Susan Løvstad Holdt

Seaweed farmers (practitioners)
- 8- Havhøst farmers (Joachim Hjerl - Founder)

Marine Educators
- 9- Lone Thybo Mouritsen (Kattegat Center)
- 10- Michael Palmgren (Malmo Marine Education Center)

Seaweed industries in DK
- 11- Algae Center Denmark
- 12- Pure Algae
- 13- Dansk Tang

Other marine biologists working with marine environments in DK (i.e. nature-based solutions, mussel and eelgrass restoration)
- 14- Cintia Organo Quintana (Southern University of Denmark)
- 15- Mads Fjældsø Christensen (Vejle Municipality)

Dorte Krause-Jensen[1]
Professor

Institut for Ecoscience
- Marin økologi
Aarhus Universitet

dkj@ecos.au.dk
+45 61860618

Specialisation:
- Macroalgae harvest

Annette Bruhn[2]
Seniorforsker

Institut for Ecoscience
- Marin økologi
Aarhus Universitet

anbr@ecos.au.dk
+45 2963803

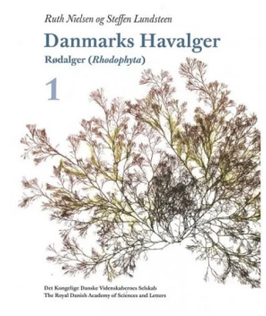
Specialisation:
- Macroalgae harvest

Teis Boderskov[2]
Forsker

Institut for Ecoscience
- Marin økologi
Aarhus Universitet

tebo@ecos.au.dk
+45 60919639

Specialisation:
- Macroalgae harvest



Ruth Nielsen
Lektor emerita

Statens Naturhistoriske Museum,
Københavns Universitet

ruthn@snm.ku.dk

Steffen Lundsteen

Institut for Ecoscience
- Marin økologi
Aarhus Universitet

Specialisation:
- Macroalgae harvest

REFERENCE

1. https://pure.au.dk/portal/da/persons/dorte-krausejensen(f866cf43-1206-44ac-98aa-dd2f160cc85c).html
2. https://pure.au.dk/portal/da/persons/annette-bruhn(15559017-3036-4e04-968e-338a24d800ce).html
3. https://pure.au.dk/portal/da/persons/teis-boderskov(c63d7c51-d48b-4a3f-a126-3b71bd450fc6).html
4. https://snm.ku.dk/english/staffsnm/staff/?pure=en%2Fpersons%2Fruth-nielsen(3ee9a66e-4e58-466b-b795-582ea7ab71b-f)%2Fpublications.html&filter=research&page=4
5. https://food.ku.dk/ansatte/?pure=da/persons/19897 E: ole.mouritsen@food.ku.dk
6. https://food.ku.dk/english/staff/?pure=en/persons/169127 E: mth@food.ku.dk
7. https://orbit.dtu.dk/en/persons/susan-l%C3%B8vstad-holdt T: 93518922 E: suho@food.dtu.dk
8. https://www.xn--havhst-eya.dk/moed-joachim-hjerl/ T 2612 0048 E: joachim@havhoest.dk
9. https://www.kattegatcentret.dk/om-os/medarbejdere/lone-thybo-mouritsen/ P: +45 20 27 65 53 E: lm@Kattegatcentret.dk
10. https://www.smkc.se/om-oss E: michael.palmgren@smkc.se
11. https://algecenterdanmark.com/
12. https://www.purealgae.dk/
13. https://www.dansktang.dk/
14. https://portal.findresearcher.sdu.dk/da/persons/cintia T: +45 65 50 91 91 E: cintia@biology.sdu.dk
15. https://www.vejleaadalogfjord.dk/interessenter/mads-fjeldsoe-christensen T. 21 29 30 14 · E: mafch@vejle.dk

STEP V. Engage with stakeholders & simulation tools/calculations

Engagere med interessenter og simuleringsværktøjer/beregninger

Involvement of relevant stakeholders:

- **Local municipalities (i.e. urban planners)** - for legal permissions on use of coastal areas
- **Citizens and educators** - their involvement in increasing awareness and how these blue spaces can be better accepted by the people and designed for the public
- **Practitioners and experts (i.e. experienced landscape/seascape architects, marine biologists and coastal engineers)** - their expertise in how to best cater to the marine life forms and how they can perform their ecosystem services based on the information given in the previous steps 1-4 and experiences to other similar projects done in other contexts

The importance of tools to help quantify and measure the potemtial impacts of seaweed:

- **Simulation software**[1] (and other appropriate tools and calculations) to help simulate and predict the potential impact of seaweed against the local conditions. For instance,
  - Calculation of wave attenuation and erostion mitigation potential of kelp farms[2] (or other marine vegetation)
  - Calculation of carbon sequestration potential of seaweed (or other marine vegetation)
- **Monitoring** with marine biologist over a a time period of time to see the improvement in biodiversity and thus, be able to predict better the impact on its local biodiversity in the future.

FOOTNOTE

1. Article on the limitations of computer modelling softwares: https://videnskab.dk/teknologi/computer-modeller-af-havmiljoet-kan-vi-stole-pa-dem/
2. Large scale kelp application: https://www.frontiersin.org/articles/10.3389/fmars.2023.992179/full

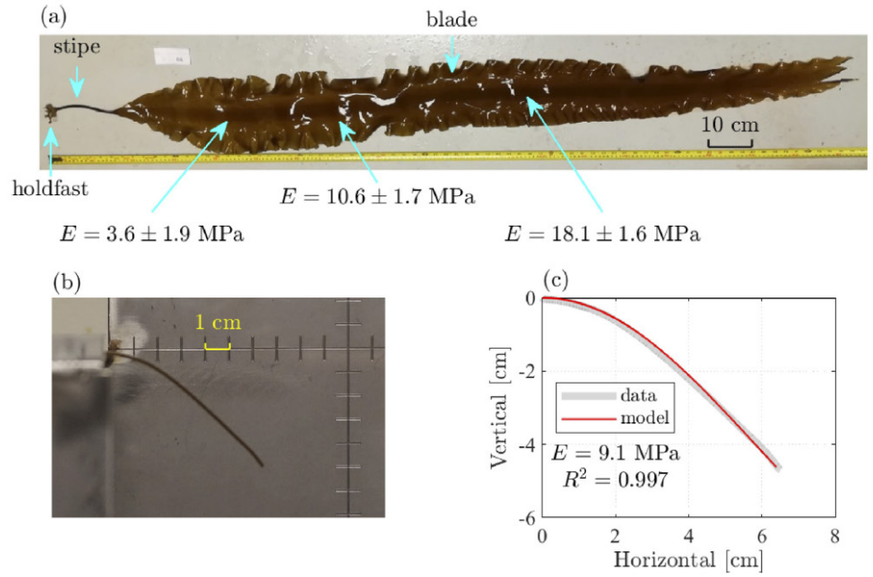


Fig. 2. (a) *Saccharina latissima* sample with bending elastic modulus (E) at three positions along the blade length. (b) Bending test for a specimen. (c) Comparison between the measured and calculated blade postures. The measured E is the value with which the calculated blade posture has the largest R^2 compared with the data. Photo credit: Yu-Ying Chen.

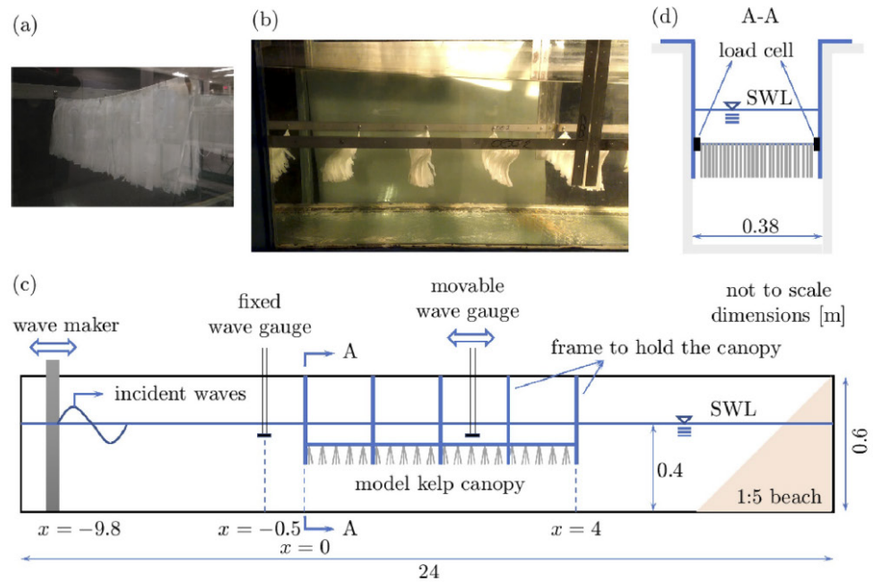


Fig. 3. Photos of (a) a model kelp longline and (b) the model kelp farms with waves propagating from left to right (see video S2 for the video in the supplementary materials). Sketches of (c) the side view of the wave flume showing the setup of model kelp farms and wave gauges and (d) the front view of section A-A showing the setup of load cells.

Figure 15. Examples of modeling and calculations involved in simulating the potential wave attenuating impact of a floating kelp farm installation. Image credit: Zhu et al. (2021)

REFERENCE

Zhu, L., Lei, J., Huguenard, K. and Fredriksson, D.W., 2021. Wave attenuation by suspended canopies with cultivated kelp (Saccharina latissima). Coastal Engineering, 168, pp.1–20. https://doi.org/10.1016/j.coastaleng.2021.103947.

Design Process - application

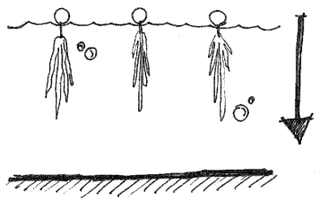
Design proces - ansøgning

An example of a challenging scenario in Denmark to implement an Urban Seascaping project

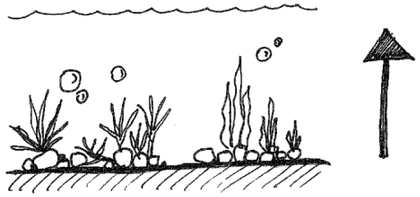
If the site is in a challenging condition with lots of nutrients, poor water clarity and pollutants, then it would need to be first “cleaned” with mussels which absorbs nutrients/pollutants more efficiently than seaweed (or eelgrass). The mussels also do not need light conditions (but cannot be in warm water temperatures and be exposed for a long time without water). The mussels can be easily installed by dispersing them into the sea bed (if the conditions are too muddy, they will not have anything to attach themselves to, so a substrate on the sea bed may need to be provided such as coconut mats or stone/rock reefs).

The mussels on lines are much more extensive and expensive way to introduce mussels for water cleaning purposes. They are best in places where there are an imbalance of food webs (i.e. too many-crabs that eat the mussels due to the lack of big fish predators), so mussels can be hung on a line to prevent crabs (or starfish) from eating too much of the mussels.

There are two main ways of growing seaweed - either from floating buoys from above or from stone reefs (or other hard substrates) from the sea bed.
Most types of seaweed (red, green and brown macroalgae) can be grown by these methods (if the conditions are right). For instance, a particular specie of seaweed (i.e. small sukkertang) are attached to the ropes which is either suspended on buoys or the ropes[1] are wrapped around the rocks. Eventually, the seaweed (or mussels) will gravitate towards the rocks and settle on them.



Option 1: Floating buoys



Option 2: Stone reefs

Refer to the Seaweed Catalogue for examples of different projects that have implemented these systems in an urban context.

Figure 16. Majority of Danish coastal waters are in poor ecological conditions and would require certain level of "cleaning up" before larger scale urban seascaping projects can be implemented. Image credit: Soo Ryu.

Figure 17. Blue mussel beds (spraying them on the sea bed) are the easiest and most effective and affordable way to clean up the coastal waters, however, the local food chain needs to be investigated to ensure that the crab and starfish population (in the absence of big predatorial fish) won't undermine the mussel bed plantation by eating them up. Image credit: Sund Vejle Fjord.

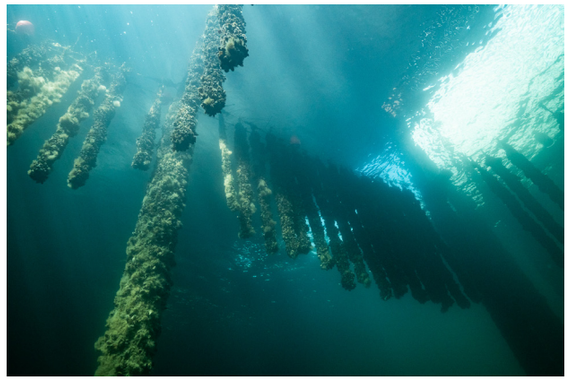


Figure 18. (Left) Another way to implement mussels beds from floating buoys to prevent crabs from eating them while they filter and clean the water.
(Right) The smaller mussels and seaweed can be attached to ropes which can be wrapped onto rock reefs to control which speicies of seaweed to grow. Image credit: Havhøst.

REFERENCE

1. Ropes used for being wrapped around the rocks to transfer a particular type of seaweed (mussels), needs to be made of a thin ecologically degradable material over time.