Feasibility Study of West Estonia
Aquaculture potential and circular economy 2020-30

The Report is framed according to guidelines stated in the public procurement reference number 232693

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1. The Feasibility Study - purpose

This Report illustrates various strategic directions which the West Estonia Region and its Municipalities should consider to structure, establish, and motivate stakeholders so that various aquaculture production initiatives aimed for the West Estonian coastal zone for the period 2020-30 can be materialized. Such strategies include the following:

- Illustrations of the production potential of large rainbow trout biomass/harvested volumes, farmed by various technical platforms.
- The potential of integrating aquaponic setup with fish production for cultivation of both mussel and macroalgae illustrated with yearly aquaponic harvest biomass.
- New farming techniques and the link to aquaponic integration may reduce the normal waste fluxes to the environment by farming rainbow trout.
    - These fluxes are shown for open nets, fish tanks on land and for semi-enclosed floating fish bags in the sea.
- These updated flux performances are illustrated by use of the latest Baltic fish feed 2021 and the fluxes are benchmark against the current Water Act thresholds for nutrient fluxes from fish farming setup for the West Estonia.
- Illustrations of potential circular economy, how it can be arranged where new initiatives can exploit the marine resources.
- Suggestions how West Estonia region best could organize the way forward.
- Highlight the risk elements related to such circular economy introduction.

These main tasks are illustrated below and summarized as:

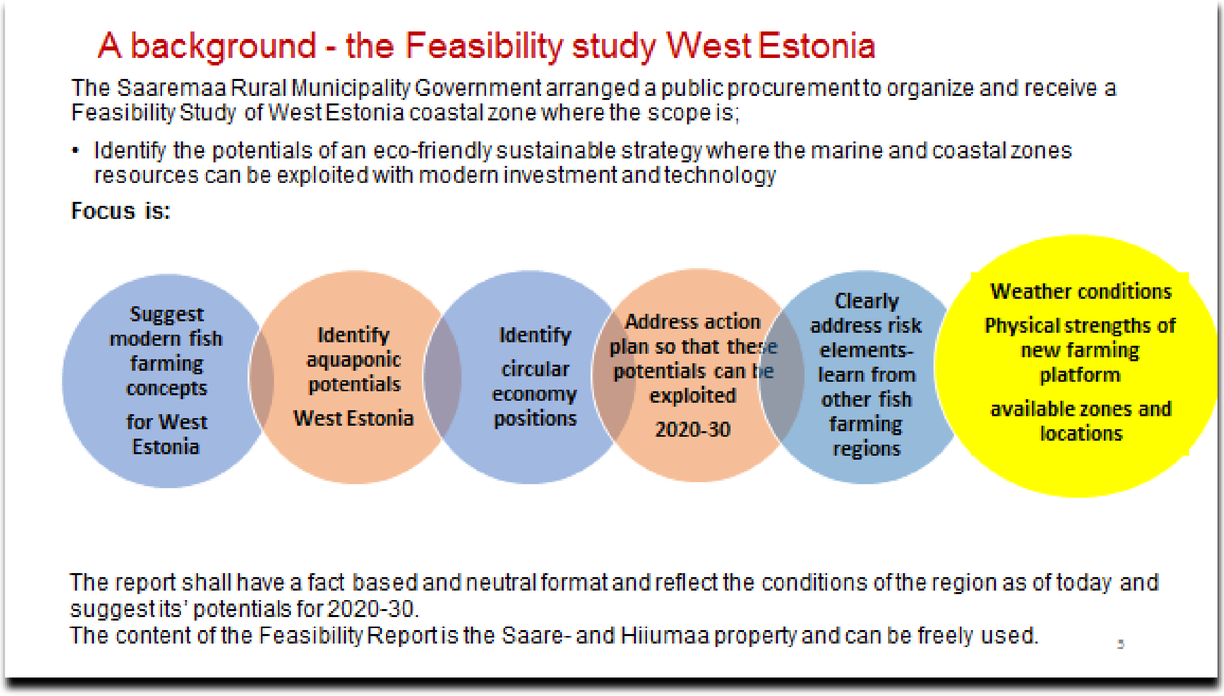


Figure 1. Scope of the analysis.

The main purpose for this Report is to suggest mechanisms and strategies to the West Estonia Municipalities (WEM) of a way forward where the aim is to exploit its marine resources. One of the intentions is to allow WEM to receive objective neutral suggestions so that its stakeholders could initiate discussion, decision for a way forward where its resource exploiting are framed over modern, sustainable and environmental setup and knowledge framed over the conditions of the Baltic Sea as such.

Therefore this report recommendations and suggestions for the exploiting of West Estonia marine resources ahould be carefully evaluated, and WEM should form its final decisions also based upon other documents and inputs. Aquaconsulting Senstad is not responsible for any outcome, positions if WEM should follow up this report observations. The same position is also for the aquaponic contributions provided by Jonne Kotta and Georg Martin, University Tartu. WEM nor any partner/business relationship WEM creates can sue/claim the authors for direct nor indirect loss, we are also not responsible for any customer's nor its customers clients direct nor indirect loss, loss of earnings related to our contributions and suggestions.

Other levels of fish farming planning, it's biomass density, it's feed demand and the fish feed in use will show other fluxes of waste, so will also other mechanical water filtration setup. Our observations is based upon a standard well used water filtration, moderate fish biomass density and one of the commercial fish feed available in the Baltic region today. Density and cultivation techniques for the mussel and macroalgae will also influence the final performances. The flux reduction per kg fish produced should however be relevant and be within reach based upon our knowledge to date.

WEM with it's local knowledge and expertise specially related to environmental conditions, mapping its coastal zone for various exploiting positions should allow dedicated zones/ locations to be allocated for aquaculture activities.

2. Executive observations

West Estonia region has updated some terms for aquaculture activity-mainly address as the Water Act which sets maximum waste/nutrients flux quantity to sea per kg fish produced;

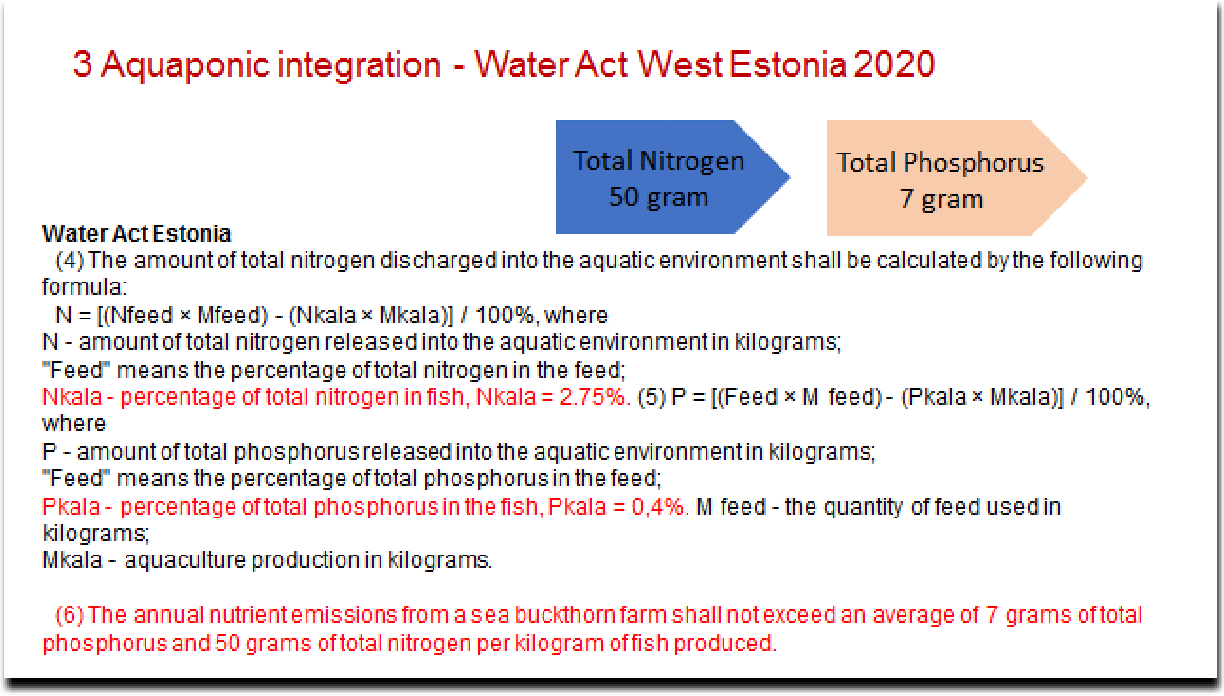


Figure 2 Water Act threshold per kg fish produced.

The Act have specified the maximum total flux of Nitrogen as 50 grams per 1 kg fish produced and a 7 grams Phosphorus per kg fish produced. The Act is not splitting between dissolved nutrient to the free water column nor the proportion bound to particular materials. Norway and Denmark have very much the same assimilation factors for Nitrogen (2.75%) and Phosphorus (0.4%) as West Estonia.

West Estonia has not specified nor quantified zones, sites and total yearly flux quotas to the dedicated zones where aquaculture activity could be establish. It would be very useful if public stakeholders do consider the best locations with minimum of environmental disturbances.

These undefined factors do result in an uncertainty for the coastal zone`s members and special for private stakeholders who have an interest in establishing circular activity in West Estonia:

a) West Estonia lacks motivation terms for aquaculture investors to take decision - biomass volume, nor flux quotas per site, per region, per year are defined.
b) This represents uncertainties and risk factors
c) The aquaculture sector in West Estonia today is fragile, lack major partners that could lead the way forward.
d) Commercial fish farming activity exists in Finland, Sweden and Denmark; however, each individual permit is very small - they lack permits that could survive for a longer period with a good foundation of economy of scale, such elements is important to consider for West Estonia.

    a. Farming activity in West Estonia is very small and does not represent any robust economy of scale.

e) There are a few applications for offshore open net farming - the final outcome is not yet made.
f) Many previous public grants have failed to motivate and initiate active farming and marine cultivations.

An illustration of the circular economy as of today.

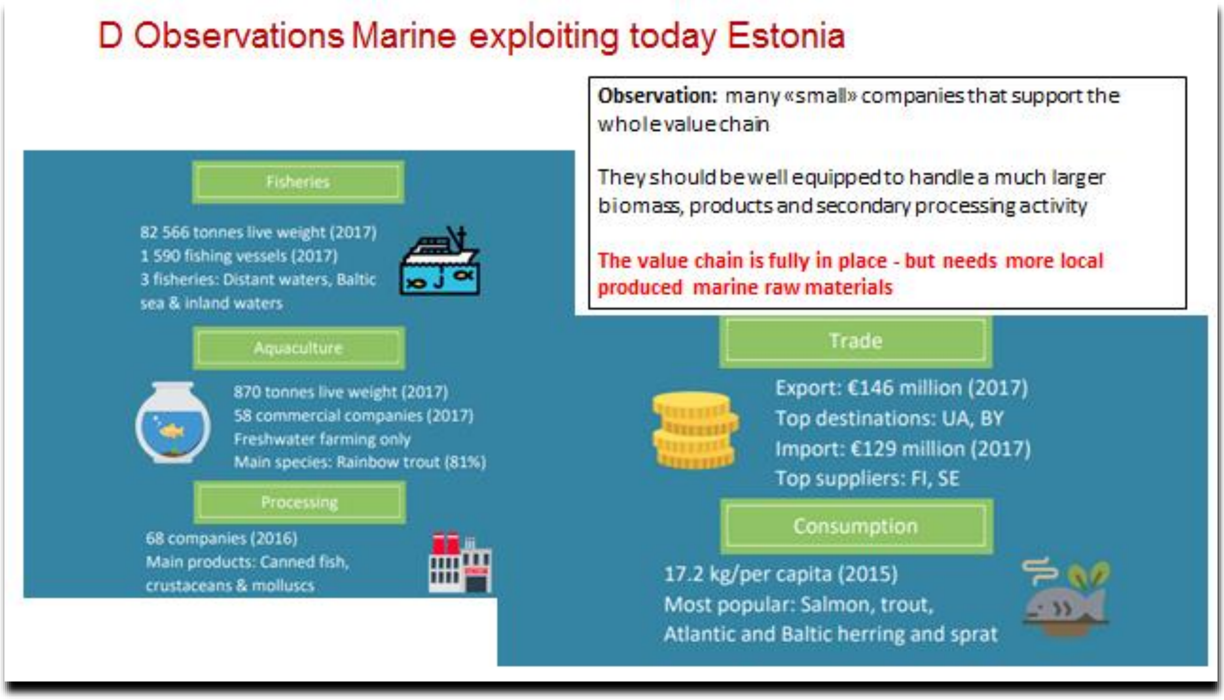


Figure 3. Circular economy of coastal zone.

The zone seems to have all elements of a required value-supply chain; however, their sizes are small and there is too little marine raw materials available. It seems also that the processing industry involving with both catches, processing the pelagic fish quotas is representing a volume scale which could be integrated toward a future fish production in the form of large rainbow trout.

<u>Suggested fish farming platforms and production potential 2020-30;</u>

a) Authorities must update flux information for the latest **Baltic fish feed 2021**- do represent a major reduction of nutrient flux to sea.

b) **Traditional Open net farming** with modern techniques could result in a production of approx. 20 000 tonnes rainbow trout per year- this is a conservative estimate. This is illustrated below where 20x sites of which 10x of these yearly have large harvested fish and the other half have always small fish. An annual harvest can then take place for 10x sites each conservative harvesting 2 000 tonnes live weight- sum 20 000 tonnes per year.

- Each site could in theory be 5 km apart and harvested biomass per average km^2 is only 20 tonnes, see illustration- which should be environmental friendly and also trigger a good foundation for optimum fish health, low interference between sites and year-classes.
- This alone could represent a **circular economy of approx. 270 jobs and value of > 175 mEUR/year, for details see below.**

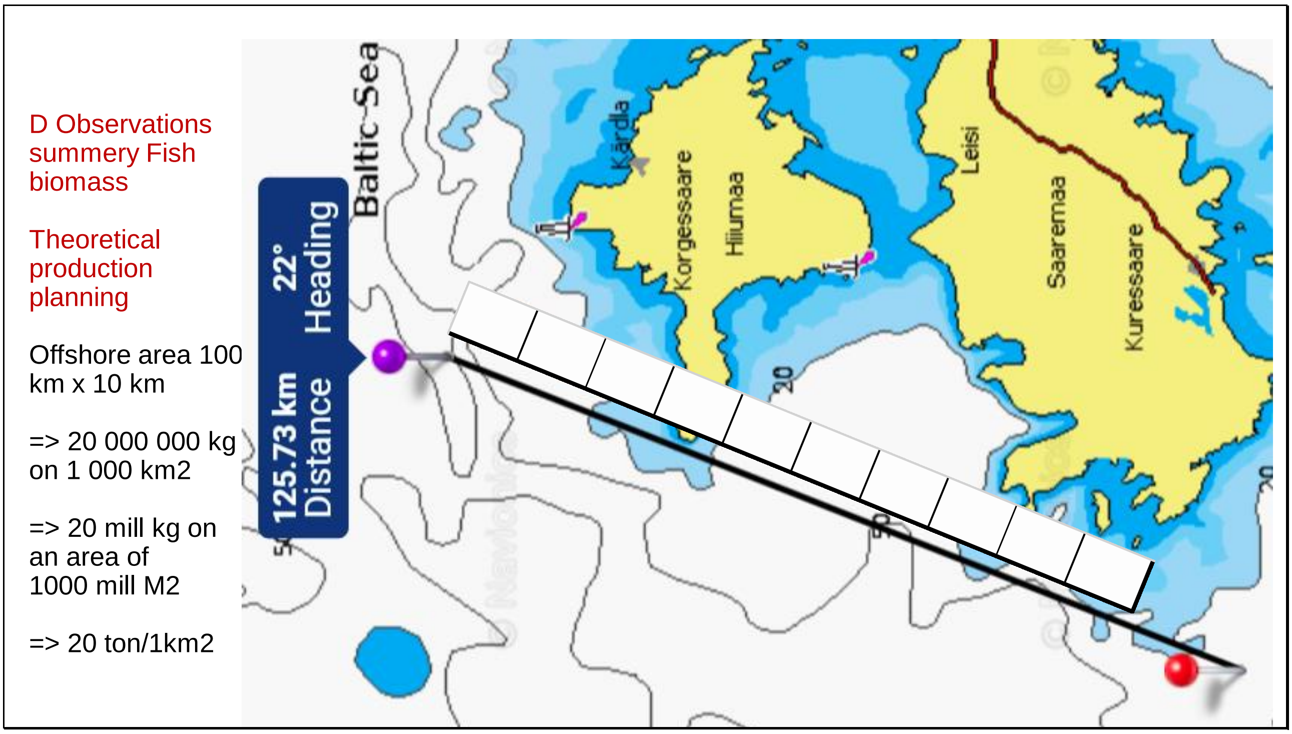


Figure 4. Illustration of theoretical Open net farming zone with potential distance apart each location.

<u>Other potential modern fish farming platforms for West Estonia are as follows:</u>

a) **Modern land-based fish farming with mechanical water filtration where** the organic wastes i.e. can be withdrawal from the water flux to Baltic Sea is illustrated where 55% of the organic fluxes is reduced, treated and is not entering the marine environment. The reduction of Nitrogen and Phosphorus by this mechanical filtration is shown in figure below. A potential of setting up 10 large on-land sites could result in **10 000 tonnes rainbow trout biomass per year- 125x jobs and a circular contribution as 90 MEUR/year.**

b) **New large floating bags concept** for sea-based fish farming do represent major new innovative solutions, special suited for Baltic Sea. The advantages which this concept shows above the standard Open net performance is

- better fish health;
- higher growth, increased survival;
- better fish quality;
- the enclosed fish bag/structure act as a protection against algae bloom and contaminations, allow for a fully oxygenated water column year-round and partly also act as a temperature control;
- further this enclosed protected water unit enables the fish farmer to have full control of the waste fluxes- which we consider to be a game changer for Baltic aquaculture and represent a key foundation for our report.

<u>Further we have integrated the on-land and the floating bag concept with an aquaponic setup:</u>

This is arrangement as illustrated in figure 5 below.

- Exploiting the natural ambient macroalga green grass *(Ulva intestinalis*) and the shellfish blue mussel (*Mytilus edulis*) will **represent large quantity of cultured biomasses.**

- **Harvesting these will result in nutrient out-fluxes from the coastal zone where**

- dissolved nutrients, as a result of the fish digestion of the fish feed, are in the steady water column out of the fish farming units and is kept inside fluxes pipes that can be directed toward similar enclosed floating aquaponic units where cultivation of macroalgae can assimilate a high proportion of such nutrient.

- However, an introduction of this farming platform must be carefully verified according to local weather conditions (currents and wave height and suitable locations with annual waste quota).
- The shellfish will physical active filter out suspended organic particles from the same fish holding units, these particles are directed in a closed pipe loop toward similar mussel bags.
- The mussel capturing organic materials results in reduced waste fluxes year-round, the photosynthesis by the macroalgae will assimilate the dissolved nutrient only part of the year when there is enough sunlight that trigger such a photosynthesis.

The potential of annual produced rainbow trout from fish tanks on-land 10 000 tonnes and similar biomass form floating bag concept - shows the total potential of 40 000 tonnes rainbow trout in the region per year. Circular economy for the on-land and bag concept is approx. 250 jobs.

Circular economy by the aquaponic integration may, roughly estimated be 175x jobs.

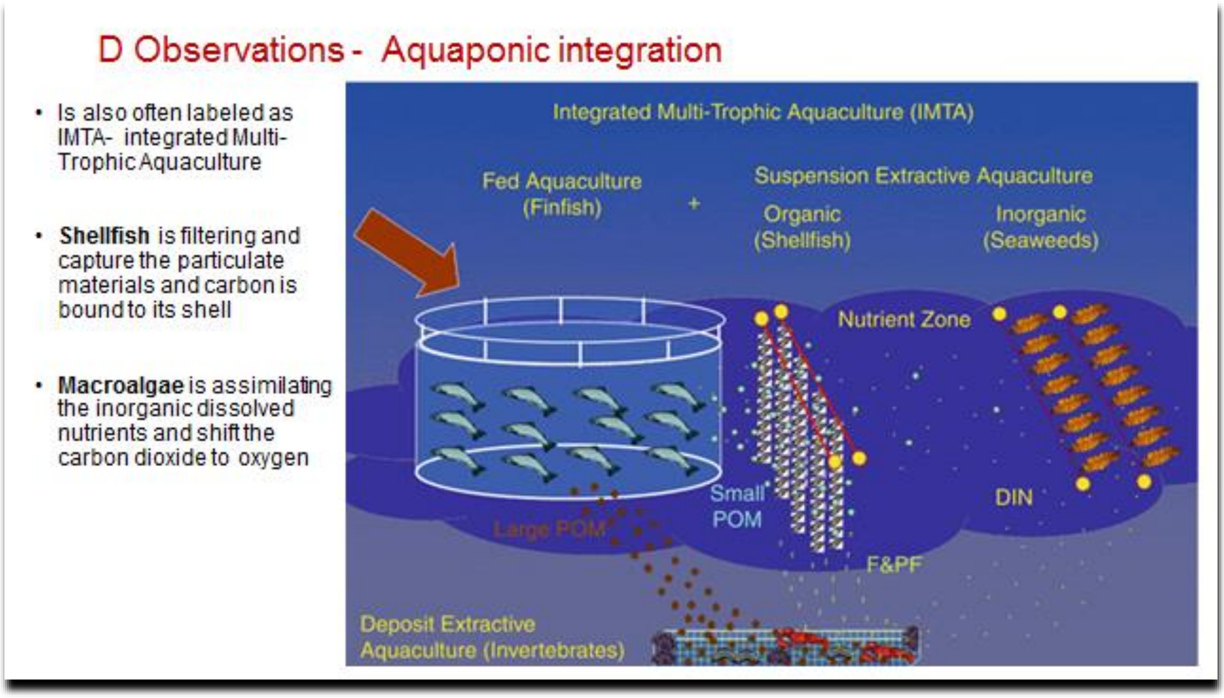


Figure 5. Illustrations of aquaponic setup.

<u>The growth potential of macroalgae *Ulva intestinalis* in the region.</u>

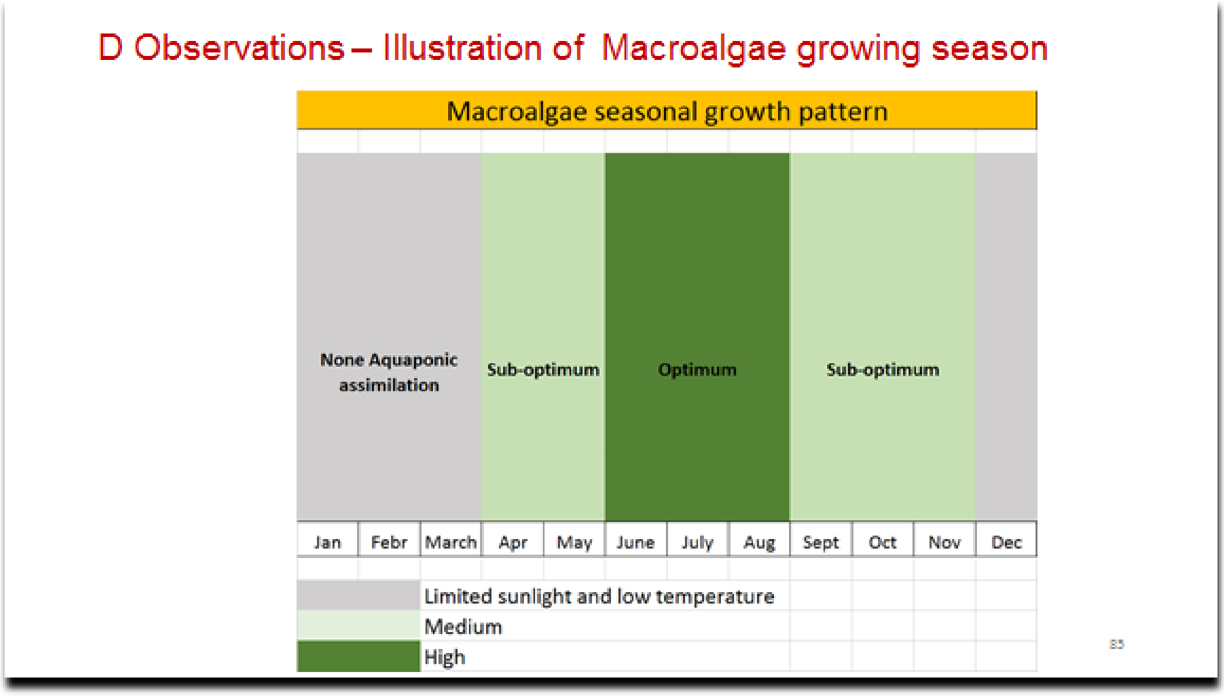


Figure 6. Macroalgae growth potential.

<u>The filtration potential of blue mussel in the region.</u>

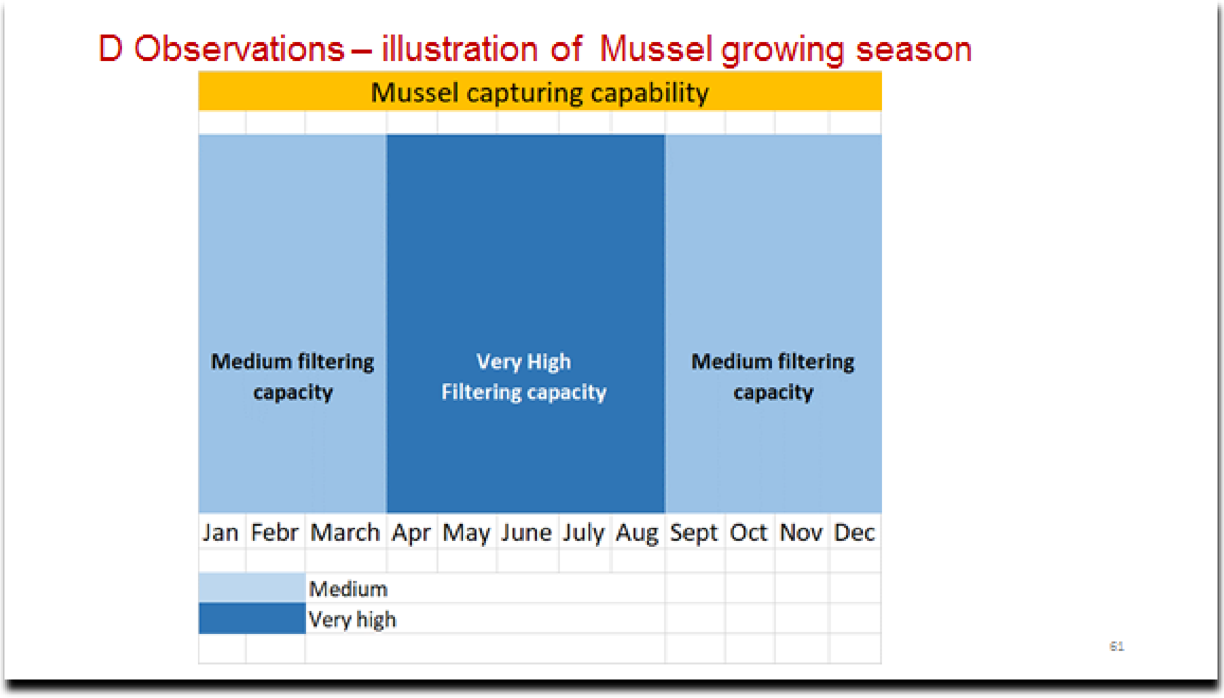


Figure 7. Blue mussel filtration performance.

For the best integration toward an **aquaponic mussel cultivation** we predict that it is best if a high proportion of the organic suspended particles form the fish units (land based or the listed floating fish bags) is first captured by mechanical water filtration units - in this report suggested as 100 micro screen. This may result that approx. 55% of the organic waste is physical taken out from the fluxes - the remaining smaller particulate fraction is then dedicated to filtering shellfish populations cultured inside mussel bags

a) The organic fish waste fraction entering mussel units can be fully captured by the filtering mussel population. This represents a zero net organic flux to sea. Fluxes of N and P which are bound to these particles is reduced see Figure 8 below.

b) Further similar arrangement can also be done with aquaponic macroalgae production - can reduce the dissolved nutrient fluxes (Nitrogen and Phosphorus) further to the next level, see Figure 8.

c) The combined water mechanical filtration, mussel and macroalgae aquaponic setup shows a potential that total N quantity per kg fish produced can be reduced by 60% compared to the threshold level of the Water Act and total Phosphorus is reduced by 90% benchmark against the Water Act, Figure 8.

d) These reduction levels of Nitrogen and Phosphorus is the average yearly levels where the macroalgae reduction in the best growing months is high and it is absent in the dark winter months (Figure 6) and where mussel more or less shows a more steady activity (Figure 7)

e) These reductions requires that the water out of the floating fish bags and tanks on-land are first directed to mechanical filtration as stated above. Other advanced filtration setups may reduce the fluxes more.

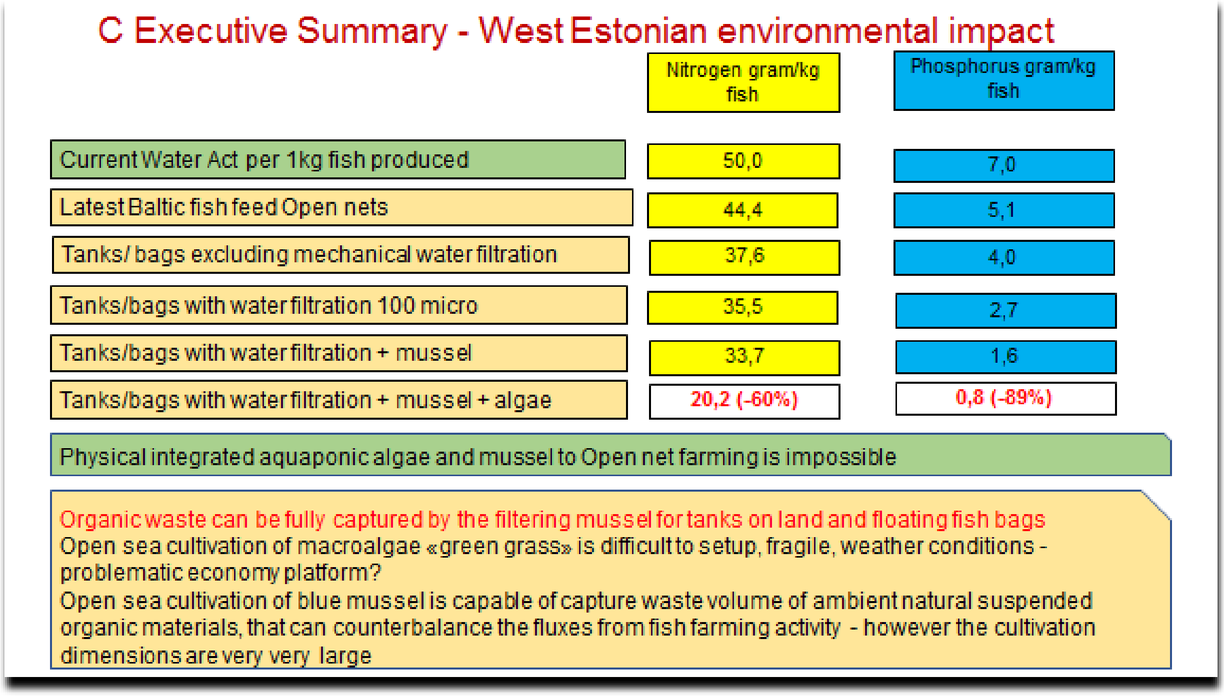


Figure 8. Gross and net fluxes with and without aquaponic setup.

<u>Comments;</u>

The Open nets strategy illustrated in this figure is having fluxes as 44 grams N and 5.1 grams P - as such water fluxes is impossible to link to mechanical water filtrations nor is it a fundament for mussel - nor macroalgae - integration.

<u>The net waste flux fully integrated with aquaponic setup may result in</u>

1. Zero organic waste to sea.
2. Nitrogen and Phosphorus levels are reduced by 60% and 89% benchmark with the maximum threshold level listed in the Water Act.

Such an integration with both algae and mussel will also reduce the carbon dioxide from the fish farming units and will end up as oxygen (algae activity) and carbonate bound to the shell for the mussel activity.

- The photosynthesis will also have the result that large amount of oxygen is produced by the algae - dissolved to the water column during daytime.
- Mussel and algae final products should be directed toward animal feed, human food, energy resource and fish feed.
- The aquaponic integration if successful will also improve the circular economy - a best guess is that this may introduce in the range of 175 jobs to the zone.

The figure below summarizes the potential of circular economy.

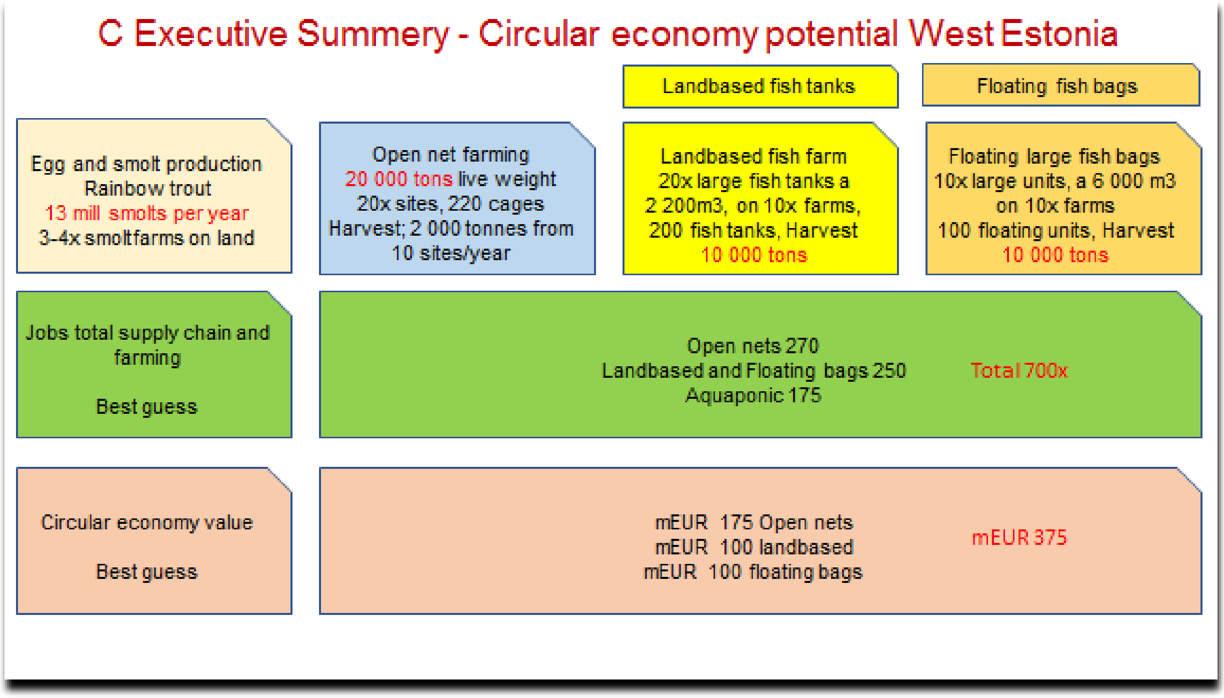


Figure 9. Potential circular economy.

If Open nets and the two illustrated enclosed farming concepts can be arranged a total of approx. 70**0 jobs, 40 000 tonnes /year live weight and 350 mEUR in circular economy** can be found - a high proportion of the jobs are related to logistic and services/ maintenance.

West Estonia Municipalities must verify this Reports findings and a way forward is to

a. Identify sea and on-land locations/zones, each with defined flux quota, we highly recommend focusing of the exploiting of the Western part of Hiiumaa and Saaremaa Islands.

b. **Update terms for aquaculture** that motives economy of scale plants to be constructed.

c. **Identify smolt farm locations** - i.e. 2-3 mill capacity each, for every 10 000 tonnes large fish one need 3.5 mill smolts- without smolt plant- no on growing activity will take place- motivation terms for these are crucial.

d. Take initiatives for a Governmental **marine lab and field station** that act as knowhow and service delivery - **extremely important -** link this to cross Nordic co-operation and make West Estonia be a leading playing partner in aquaponic integration in the region.

e. **Invite international leading industrial company to seminar**; wind energy, fish farmer, investors, secondary processing industry, local pelagic fishing companies, shipyard, Norwegian/ Scottish manufacturer of modern farming platforms. The seminar should strategically motivate partners to

- Get in touch.
- Be aware of the possibilities.
- Look towards Estonia instead of Iceland, North Sea, Newfound Land or RAS investments on land.
- All partners are 45 minutes flight from Tallinn, and all are framed under a Nordic culture and business understanding. Estonia being a major IT and IoT provider could take very good positions in such aquaponic integration.
- **Forward fact based information about the possibilities, region, conditions, companies, motive for JV.**
- **Wind energy companies** may play a major role - as Baltic Sea do need innovative solutions for maritime aquaculture constructions.
  - Set up a shared pool of service, maintenance and logistic.
  - JV
  - Construction components
  - Terms for applied wind energy licenses could certainly be linked to various requirements, one could be to establish a wind-aqua fond, where the sizes of wind park could have a price/ contribution value.
  - Such contributions could be services, kwh, cash so that the Pilot stations / marine lab could be setup.
  - The wind energy companies need service from such a station too.

f) **Secondary salmon processing industry** in France, Germany, Poland is desperate to have control of their own farming biomass, cost wise, risk mitigation, harvest and biomass planning inhouse.

g) Avoid the position which fish farmers in Finland, Sweden and Denmark do experience

h) **There is none farming licenses cost entry barrier to day**, but be smart and find an economical/ contribution friendly mechanisms for this.

i) **Risks,** weather conditions, aquaponic net result (filtering and photosynthesis capabilities inside floating units), smolt farms, political willingness, protests from neighbours, tourist and agriculture.

j) **Remark; production cost** of gutted large rainbow trout without aquaponic integration is previous been found identical as Norway.

<u>The main risk elements is illustrated below.</u>

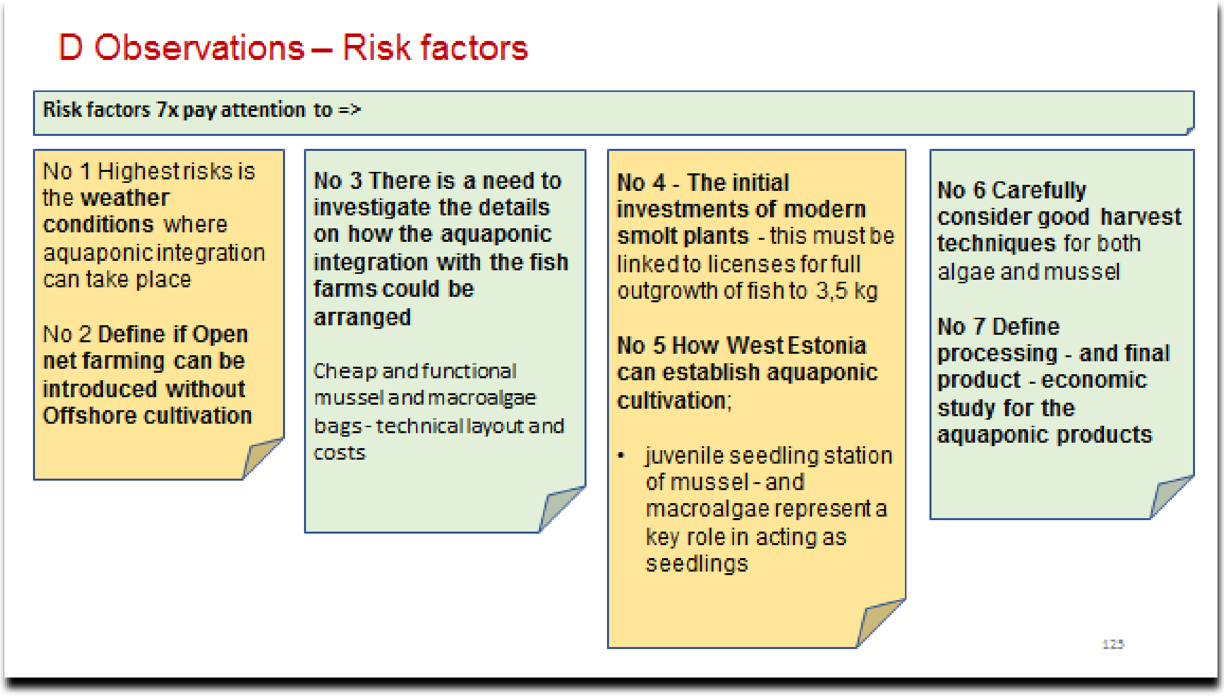


Figure 10. Risk elements.

These risk elements must carefully be evaluated.

<u>Key waste reduction findings in this report.</u>

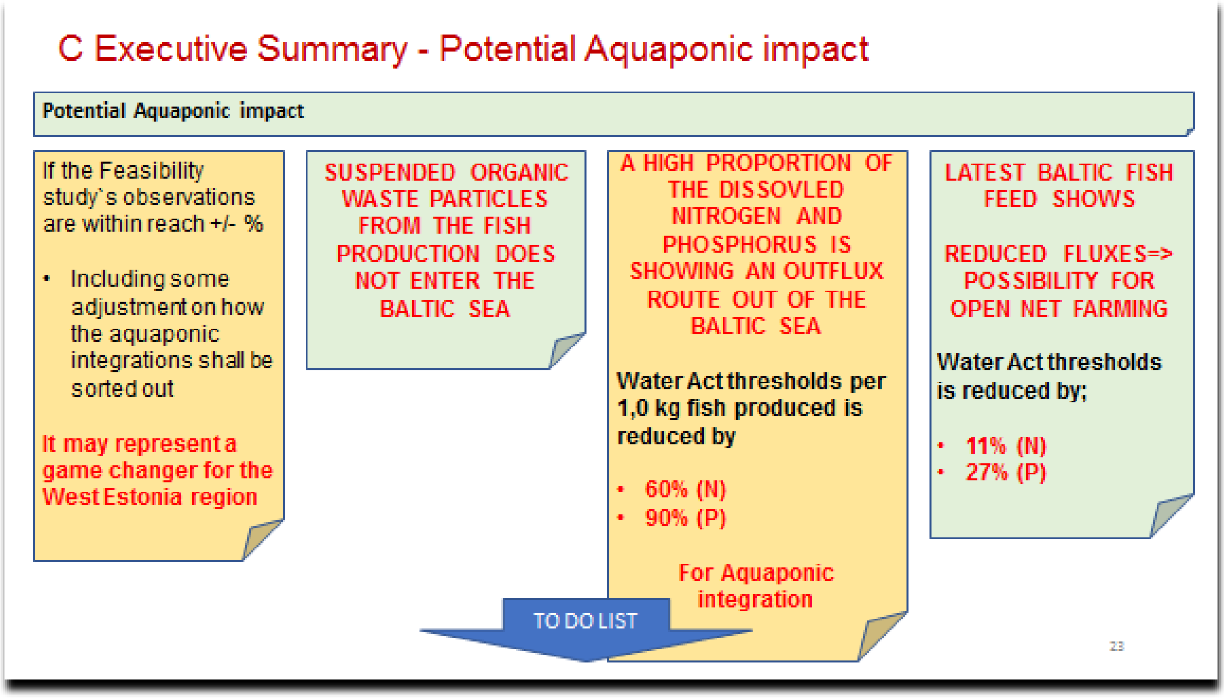


Figure 11. Aquaponic and none aquaponic flux reductions.

<u>Comments:</u>

a) <u>It is important that the suggested aquaponic physical integrations suggested here are carefully integrated in a manner where nutrients and organic wastes are conserved.</u>
b) <u>That the mussel and macroalgae are given good growth conditions.</u>
c) <u>That little macroalgae and mussel are lost to the environment.</u>
d) <u>That waste from the mussel filtering activity is also physically pumped a shore.</u>

Our recommended TO DO list for WEM.

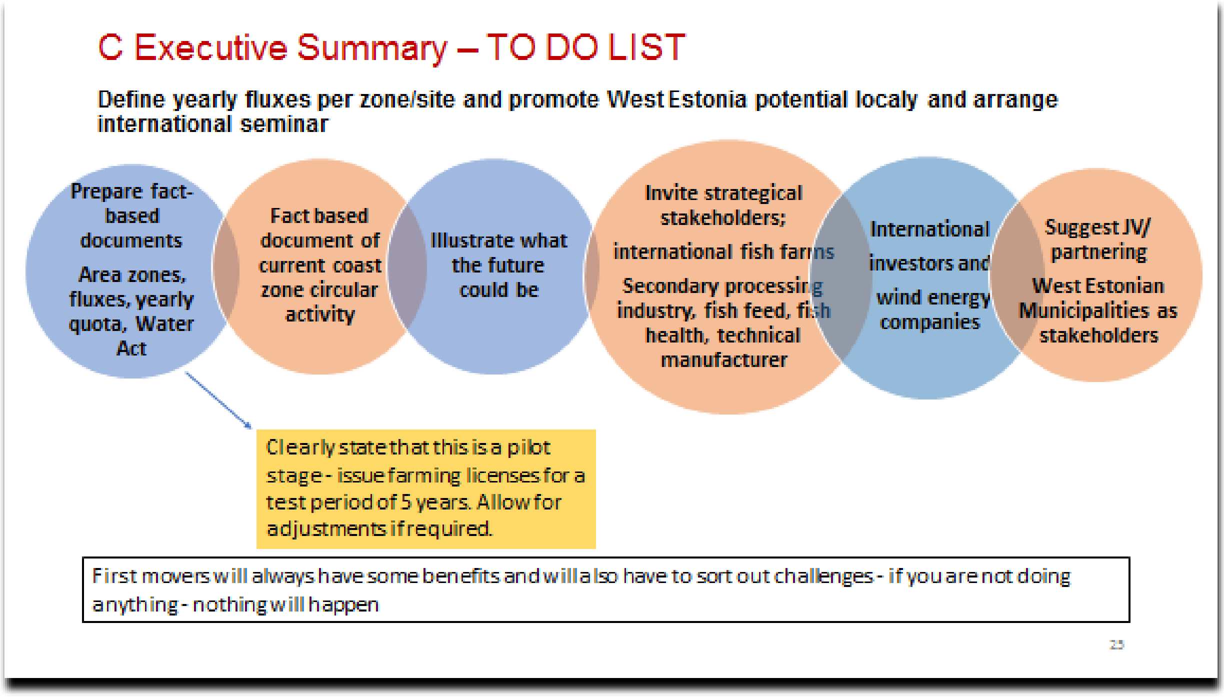
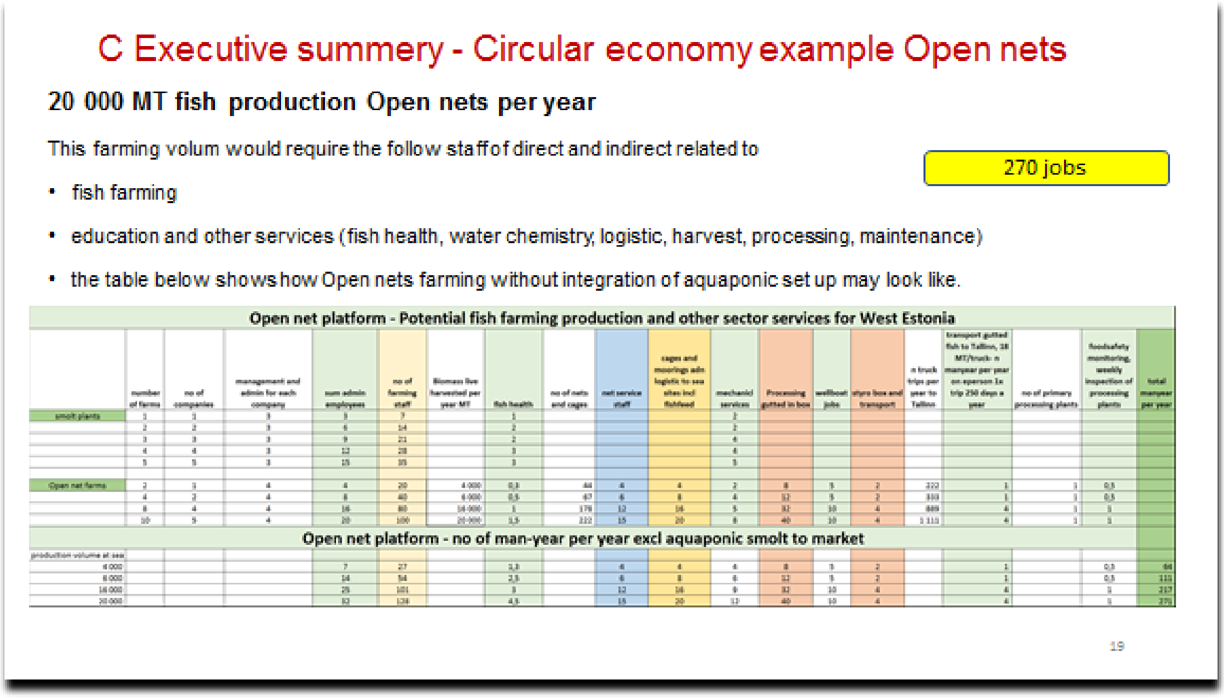


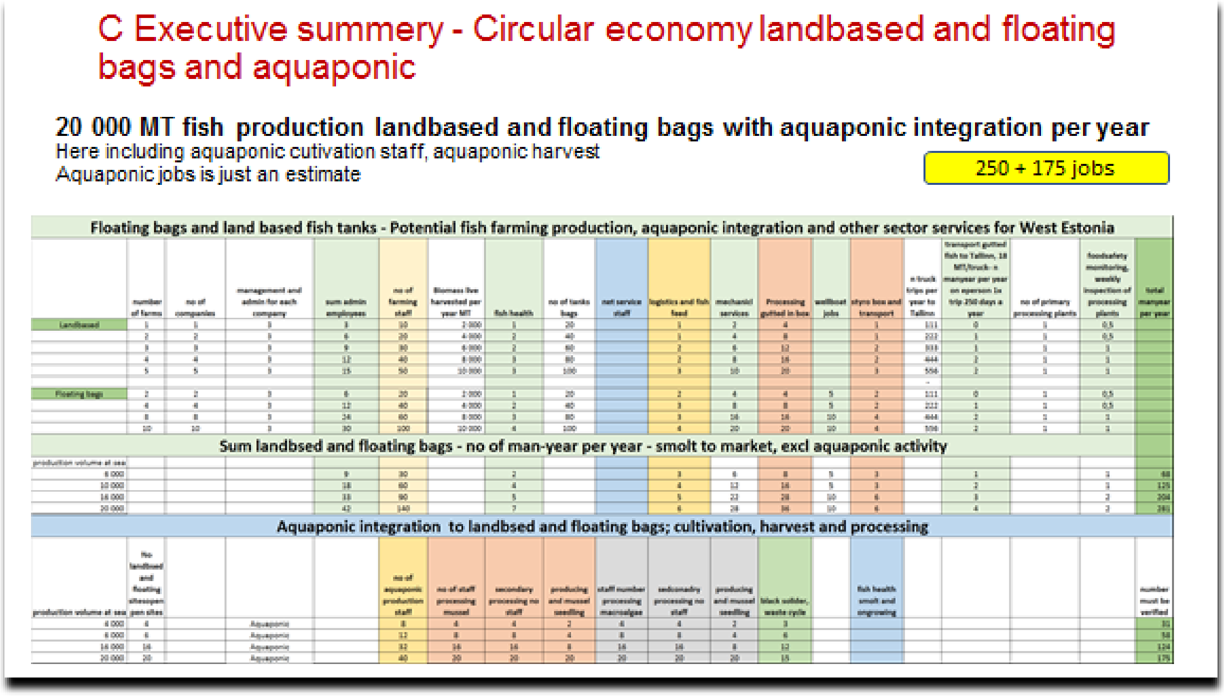
Figure 12. TO DO list.

Some details to circular economy.



Open net platform - Potential fish farming production and other sector services for West Estonia

	number of farms	no of companies	management and admin for each company	sum admin employees	no of farming staff	Biomass live harvested per year MT	fish health	no of nets and cages	net service staff	cages and moorings adm logistic to sea sites incl fishfeed	mechanic services	Processing gutted in box	wellboat jobs	styro box and transport	n truck trips per year to Tallinn	transport gutted fish to Tallinn, 18 MT/truck: n manyear per year on aperson 1x trip 250 days a year	no of primary processing plants	foodsafety monitoring, weekly inspection of processing plants	total manyear per year
smolt plants	1	1	3	3	7		1				2								
	2	2	3	6	14		2				2								
	3	3	3	9	21		2				4								
	4	4	3	12	28		3				4								
	5	5	3	15	35		3				5								
Open net farms	2	1	4	4	20	4 000	0,3	44	4	4	2	8	5	2	222	1	1	0,5	
	4	2	4	8	40	8 000	0,5	67	6	8	4	12	5	2	333	1	1	0,5	
	8	4	4	16	80	16 000	1	178	12	16	5	32	10	4	889	4	1	1	
	10	5	4	20	100	20 000	1,5	222	15	20	8	40	10	4	1 111	4	1	1	
Open net platform - no of man-year per year excl aquaponic smolt to market																			
production volume at sea																			
4 000				7	27		1,3		4	4	4	8	5	2		1		0,5	84
8 000				14	54		2,5		6	8	6	12	5	2		1		0,5	111
16 000				25	101		3		12	16	9	32	10	4		4		1	217
20 000				32	128		4,5		15	20	12	40	10	4		4		1	270



Floating bags and land based fish tanks - Potential fish farming production, aquaponic integration and other sector services for West Estonia	number of farms	no of companies	management and admin for each company	sum admin employees	no of farming staff	Biomass live harvested per year MT	fish health	no of tanks bags	net service staff	logistics and fish feed	mechanic services	Processing gutted in box	wellboat jobs	styro box and transport	n truck trips per year to Tallinn	transport gutted fish to Tallinn, 18 MT/truck: n manyear per year on eperson 1x trip 250 days a year	no of primary processing plants	foodsafety monitoring, weekly inspection of processing plants	total manyear per year
Landbased	1	1	3	3	10	2 000	1	20		1	2	4		1	111	0	1	0,5	
	2	2	3	6	20	4 000	2	40		1	4	8		1	222	1	1	0,5	
	3	3	3	9	30	6 000	2	60		2	6	12		2	333	1	1	1	
	4	4	3	12	40	8 000	3	80		2	8	16		2	444	2	1	1	
	5	5	3	15	50	10 000	3	100		3	10	20		3	556	2	1	1	
															-				
Floating bags	2	2	3	6	20	2 000	1	20		2	4	4	5	2	111	0	1	0,5	
	4	4	3	12	40	4 000	2	40		3	8	8	5	2	222	1	1	0,5	
	8	8	3	24	60	8 000	3	80		3	16	16	10	4	444	2	1	1	
	10	10	3	30	100	10 000	4	100		4	20	20	10	4	556	2	1	1	
Sum landbsed and floating bags - no of man-year per year - smolt to market, excl aquaponic activity																			
production volume at sea																			
6 000				9	30		2			3	6	8	5	3		1		1	68
10 000				18	60		4			4	12	16	5	3		2		1	125
16 000				33	90		5			5	22	28	10	6		3		2	204
20 000				42	140		7			6	28	36	10	6		4		2	281
Aquaponic integration to landbsed and floating bags; cultivation, harvest and processing																			
production volume at sea	No landbsed and floating sitesopen pen sites				no of aquaponic production staff	no of staff processing mussel	secondary processing no staff	producing and mussel seedling	staff number processing macroalgae	sedcondary processing no staff	producing and mussel seedling	black soldier, waste cycle		fish health smolt and ongrowing					number must be verified
4 000	4		Aquaponic		8	4	4	2	4	4	2	3							31
8 000	8		Aquaponic		12	8	8	4	8	8	4	6							58
16 000	16		Aquaponic		32	16	16	8	16	16	8	12							124
20 000	20		Aquaponic		40	20	20	20	20	20	20	15							175

Figure 13. Detail circular economy observations.

3. Status Baltic Sea - status

Any initiatives of modern fish farming activity, also for West Estonia, will result in waste products that normally will represent flux of organic waste and dissolved nutrients to the free water column (Nitrogen and Phosphorus). This is highly relevant for the Baltic Sea as such caused by

- being a very large marine sea area
- having limited seawater exchange in the Kattegat area where new more saline water can enter the Baltic Sea where at the same time pushes older sea out to the North Sea
- such water exchanges take place very seldom
- the whole Baltic Sea does receive waste and nutrient fluxes mainly form forest and agriculture activities for many year, wastes from modern land based industry activity and from human population causes all an increase in nutrient fluxes
- this have been the situation for many year=>
- this has resulted in an increased eutrophication; resulting in excess algae growth, excess oxygen demand, limited marine life in the deeper sea
- this situation results also in a pressure on the marine resources in general
- for a modern aquaculture perspective this has resulted in that the whole Baltic Sea is laid behind compared to the enormous growth which has and is taken place in the salmonid fish production in i.e. Norway and Scotland the last 40 years
- apart from this description the Baltic sea water masses from surface and down to -30-40 m is well suited for marine exploiting
- on land structures for farming activity with high quality waste treatment techniques is hardly present in the region
- as in most coastal and offshore regions - weather conditions as wave and current and sporadic drifting ice in the northern part of Baltic Sea do represents physical risk to marine constructions

<u>Illustrations of the main Directives and agreement for the Baltic Sea;</u>

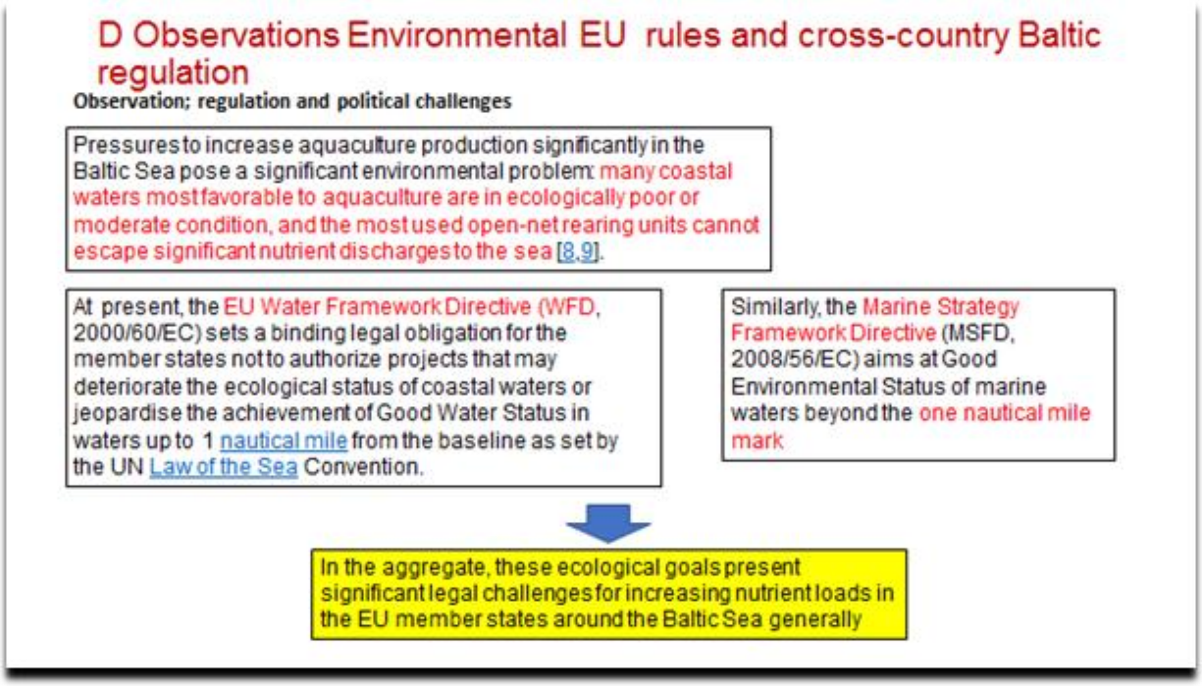


Figure 14. Regulation and Water Directives Baltic Sea.

These elements have resulted in a situation where the Baltic region has established cross country agreements and understandings to conserve and to protect the Baltic Sea. There is agreement among the countries according to the EU Framework Directive and other rules that have guidelines to be followed prior any approval of any new activity that may disturb the environmental conditions in negative directions.

Some countries do practice this in slightly different manners, and for aquaculture farming terms there are also diverting terms and conditions. There is also conflict of interest if i.e. an aquaculture activity can be further exploited, or new techniques can be introduced, and how waste flux quotas can be organized.

In some region there is a conflict of interest among the agriculture and aquaculture sectors i.e. Denmark.

A situation in Denmark as of today must be avoided;

- the open net trout farmers in Denmark has also shown a consolidation
- today there is approx. 4x farming companies
- in Denmark also fronting the Baltic Sea there have been discussions related to farming permits, possibility to use new better locations
- permits in Denmark is in principle based upon 2 elements
  - a discharge volume of x kg N and x kg P per site
  - some location has also an annual feed quota as part of the permits
  - not all farming locations has all l3 listed permits types
  - most production of large rainbow trout in Denmark is very different from other regions; they release large smolt to sea early spring, i.e. 800 gram, and harvest then as 3-3,5 kg in November, then leave the sites without any production at all, a large proportion of the biomass is actually farmed in the end as maturing fish where the target is to produce eggs for caviar sales
  - in this way a waste related to 0-800 gram takes place on land- resulting in that the annual waste fluxes per individual sea sites is "undisturbed" in this period which allows the farmers to a similar additional sea based waste volume
  - a seabed area permit
  - when these 2 permits is approved then a Danish fishfarmer can start production

    - during the last 7 years these permits have been under different public institutional responsibility, and have been managed in a way where new applications have not yet been verified, farmers are waiting for final conclusions, none new sites have been granted
    - second and more severe- all previous granted permits are today in a "limbo" situation, they are all to be verified under to-days situation
    - their outcome for final result is unknown and makes the life as a fish farmer very unpredictable and unstable
- this is NOT saying that open net farming in Denmark is stopped nor banned- it is just a re-settling and a consolidation from the authorities on how to judge waste fluxes/ permits for the coming period
- some argue that fishfarmers should move on land- but

WEM should create up to-day contact with aquaculture authorities in Norway, Denmark, Finland and Sweden to make observations, learn of success and failure so that a new growing industry in West Estonia is framed under reliable conditions and terms, creating clear objective terms and conditions and with minimum of surprises for private farming companies.

4. The main tasks behind this Report

Below is illustrations of the main tasks contributed by the authors followed by list of 11x focus area that do structure a frame of this report:

One of the main scopes of this Report is to introduce fish farming concepts (sea based and land-based units) that allows stakeholders to create eco-friend biomass production in West Estonia. New permits with new techniques may result that companies may have a good steady biomass permit which is important for the economical performances.

We predict that without such an understanding there will be impossible for West Estonia and other regions to meet future Water Directive requirements.

<u>To establish a fact-based neutral report the authors have individual key insight into</u>

- fish farming in general, fish feed and nutrition
- marine ecology – the growth potential of algal and mussel
- In-depth knowledge on the Baltic Sea where Jonne Kotta and Georg Martin have performed various aquaponic studies in the region and have further analysed this evidence in the report as well as applied the scenario fish farming biomass and its waste where aquaponic integrations are analysed.

We aim to present fact-based performances and we predict that our conclusions are reflecting the potential of fish biomass, net flux of waste to the West Estonia zone. However as with all biological modelling we have considered the following conditions.

<u>Fish farming- background:</u>

- The farming platforms (floating bags and on-land fish tanks) are avoiding that any excess fish feed from their enclosed water column do enter the environment as opposed to the traditional open net platforms where this is physical impossible.

- As the platforms represent a controlled physical barrier, the risk of having fish feed in the water column without being captured by the fish population is also reduced to minimum.

- The basic mortality of fish farmed in Open net cages is somewhat higher than what is observed from floating bags / tanks on land.

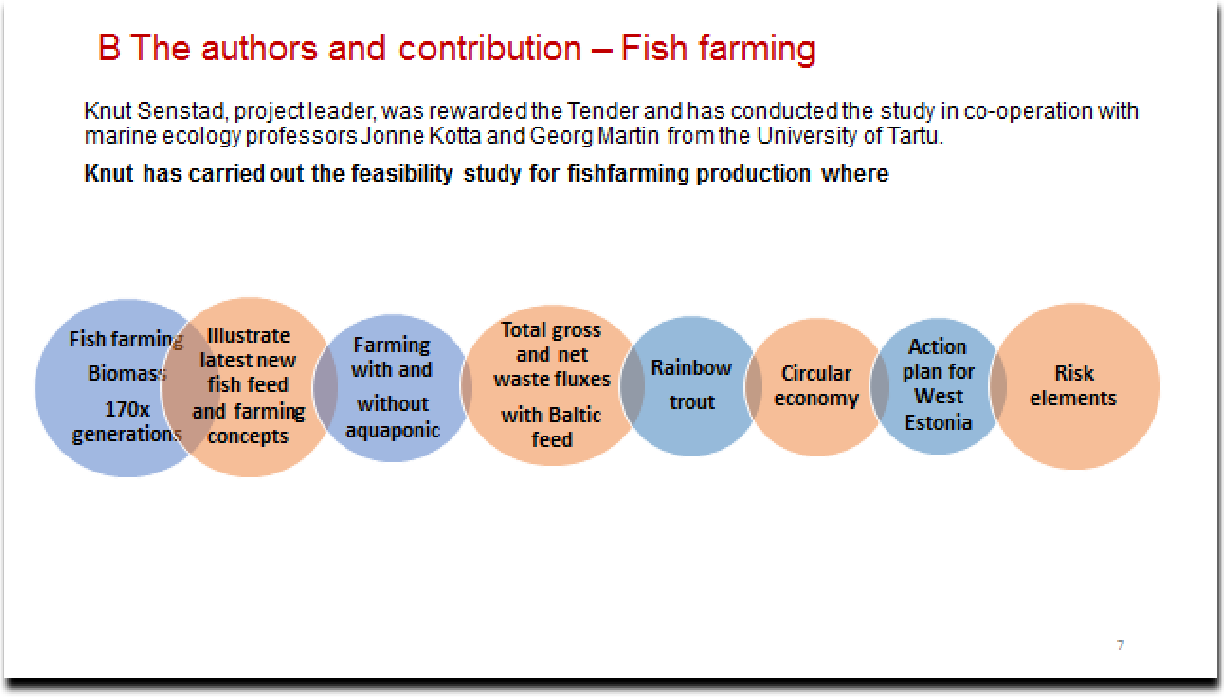
<u>Mussel aquaponic:</u>

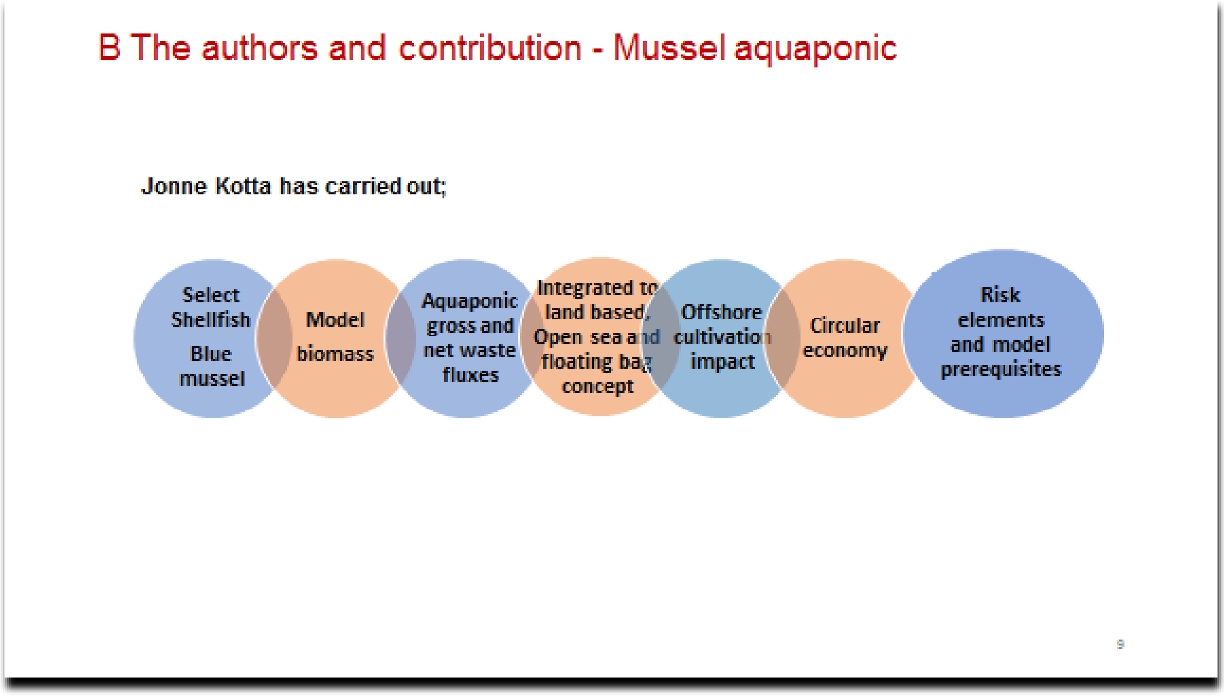
- In-depth understanding of the West Estonia conditions for natural growth, filtering potential or cultivation of mussel
- Locally tested growth model is used in this report to show the potential impact of mussel integration where the mussel received a much higher supply 24/7 of organic suspended particles from the fish holding units compared to the availability of natural suspended particles.

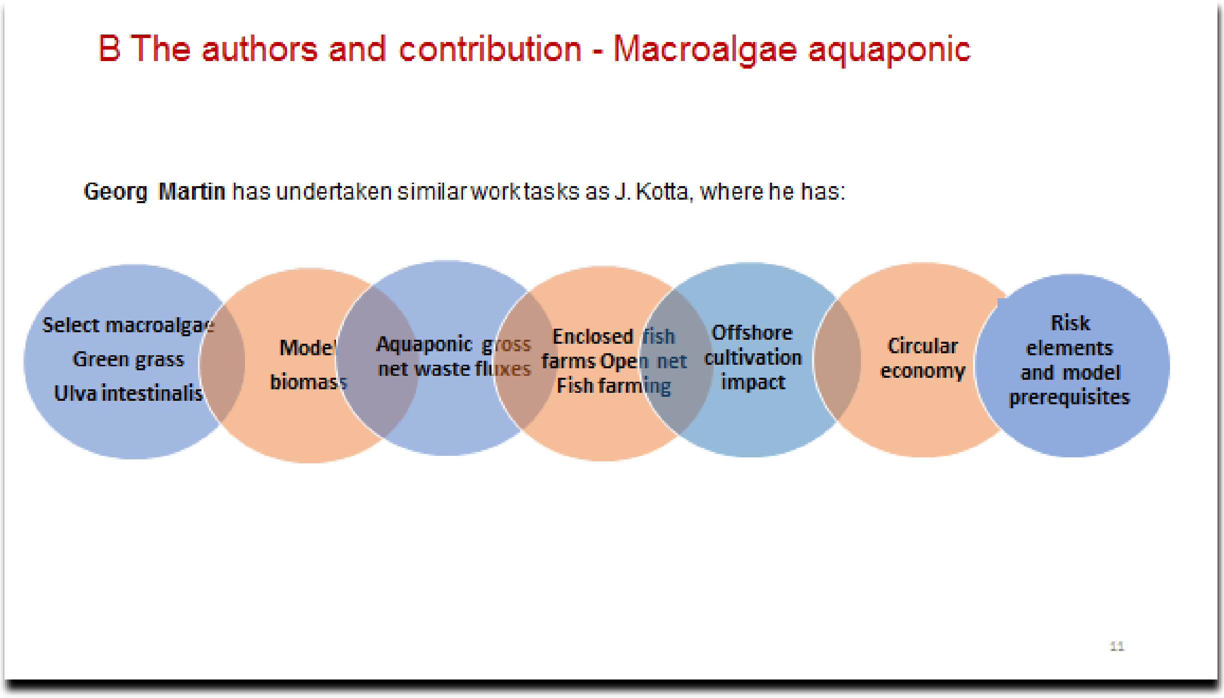
Macroalgae aquaponic:

- In-depth understanding and field experimental data from West Estonia is used where local macroalgae is held in enclosed large floating algae bags with a much high concentrations of dissolved nutrient benchmark than the macroalgae *Ulva intestinalis* was growing natural in the zone.

Below is our task contributions:







<u>Figure 15. Analyses tasks.</u>

<u>Based upon the Scope and the Report content we have focused upon 11x main areas.</u>

D Observations Feasibility study targets

11x STEPS APPROCH

These environmental- and political- constrains => exploiting the coastal zone of West Estonia may look very difficult or impossible;

- Fish farming do increase the nutrient flux to Baltic Sea - yes
- How can we reduce these fluxes?
  - NO 1 - Use the latest modern Baltic fish feed- define new flux quantities
  - NO 2 Establish RAS on land- very expensive (75 M€ for 5 000 tons farm) but can be done
  - NO 3 Look for other land-based fish platforms that is less Capex demanding How are these?, Who operate them? How functional are they? Can they reduce the waste fluxes?
  - NO 4 Look for traditional Open nets and new Offshore-based Fish farming platforms. Floating enclosed bags - Which one? Where-to? What farming results? What advantages? What flux impact?

D Observations Feasibility study target

Cont. - 11x STEPS APPROACH

These environmental and political constrains => exploiting the coastal zone of West Estonia may look very difficult or impossible;

- NO 5 How can West Estonia aquaponic integrations further reduce fluxes? If yes- what must be organized?
- NO 6 What are the net new fluxes?
- NO 7 Action point; Way forward- public stakeholders

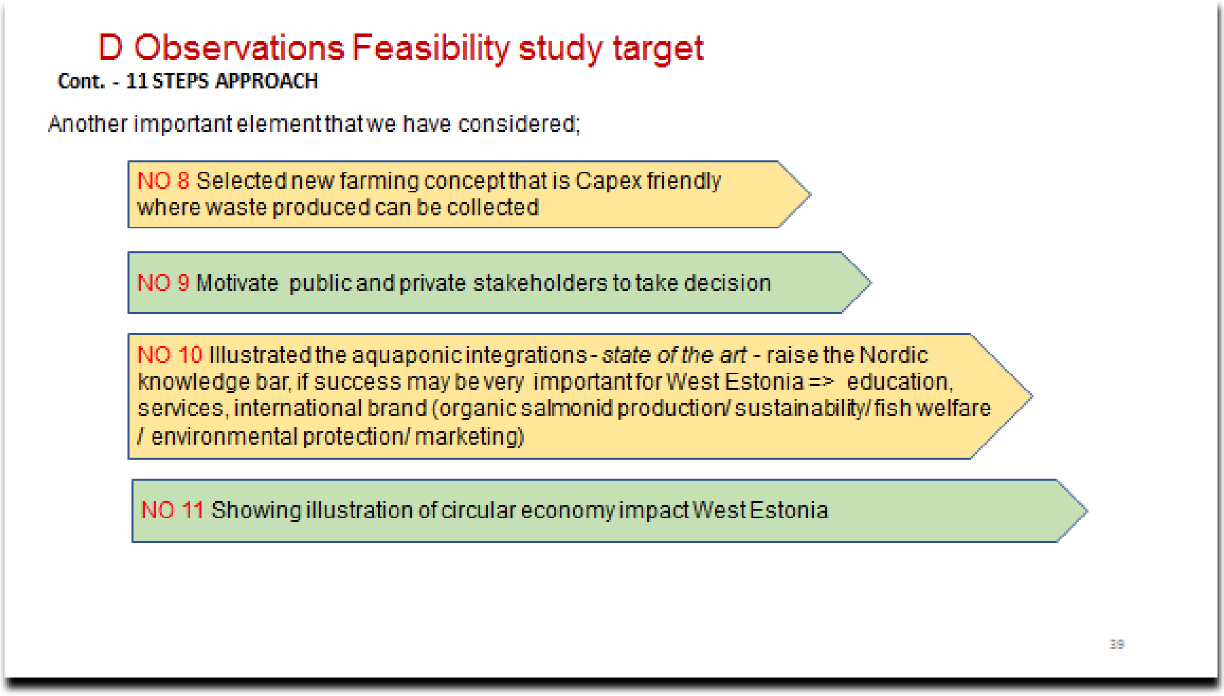


Figure 16. The 11x main task elements.

Below is a short illustration of the trends related to Western aquaculture sector activity.

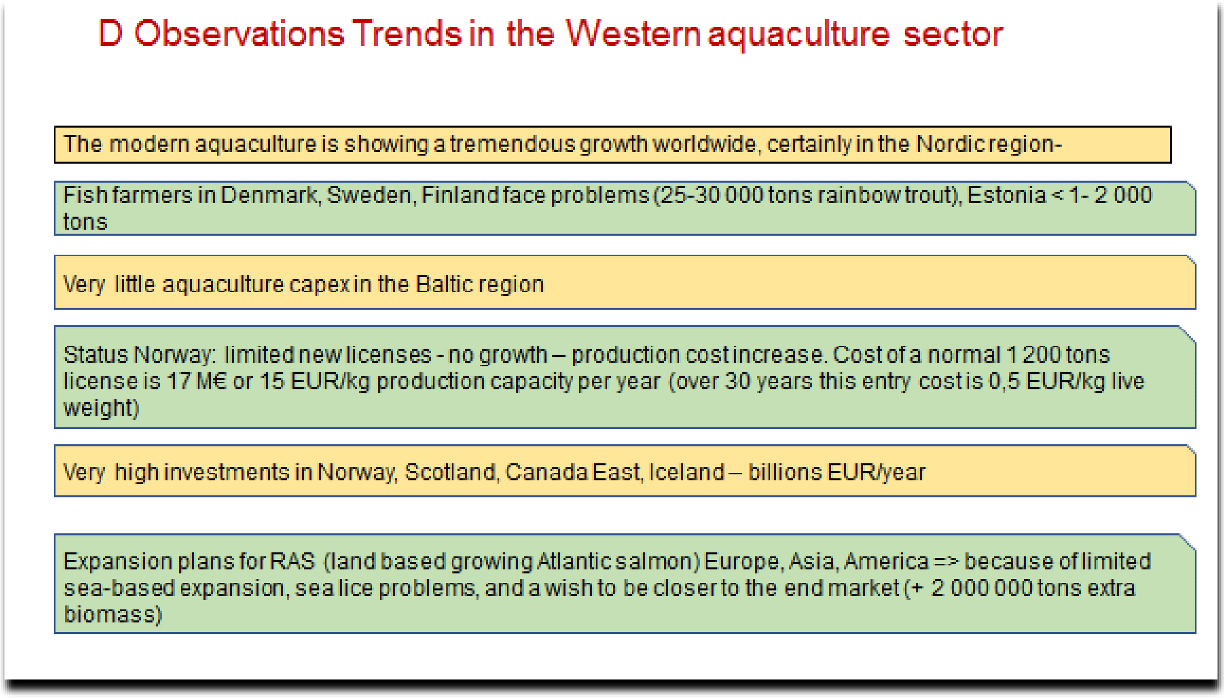


Figure 17. Western aquaculture sector.

The illustrated opportunity for West Estonia with a modern fish farming production.

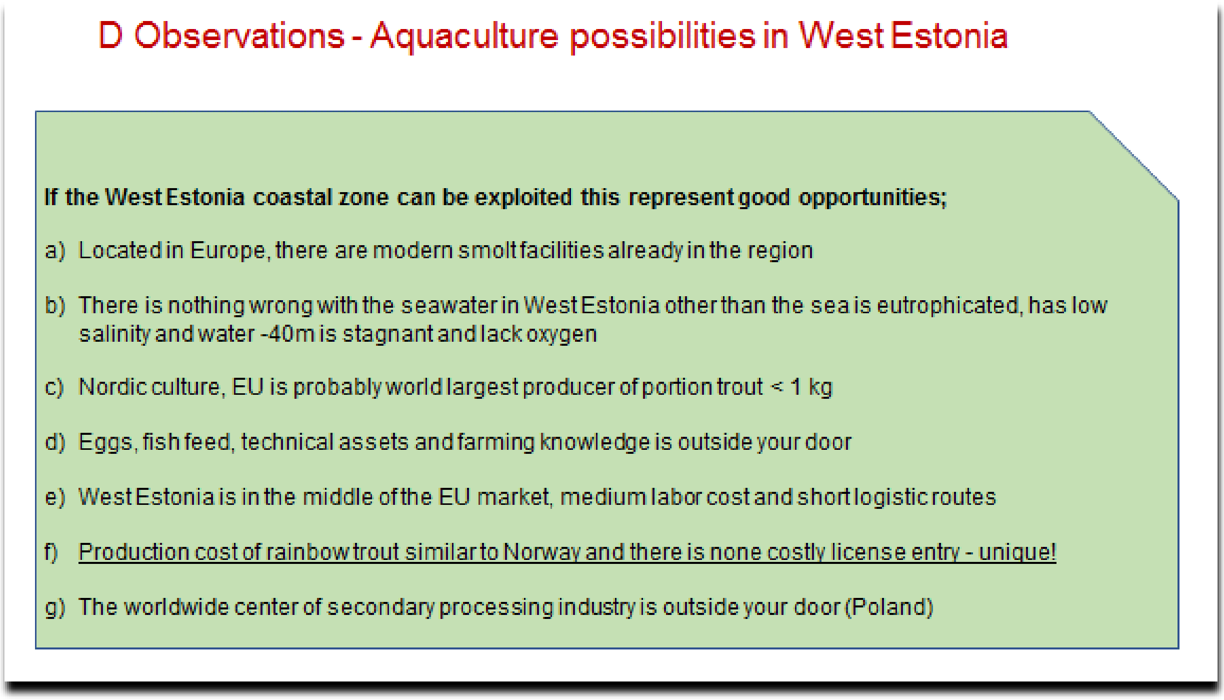


Figure 18. Aquaculture possibility in West Estonia.

5 West Estonia exploiting the marine resources

A short illustration of the various marine activity in the region.

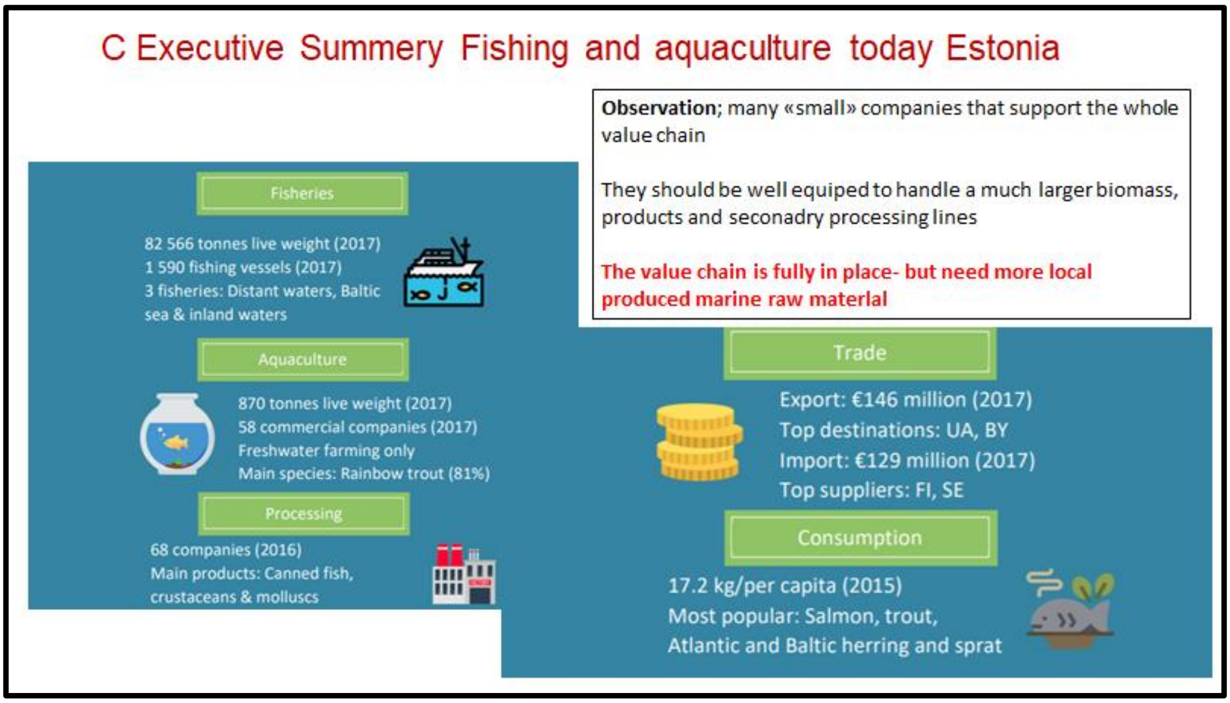


Figure 19. Coastal circular economy Estonia 2017.

Comments;

There are many small companies, a large activity is related to wild fish catches and its processing added value activities. Direct finfish aquaculture is very small. Estonia do import a lot of fish products from Sweden and Finland.

However, the region seems to have all the possibility for escalation - you have most of the infrastructure in place - it is very much related to volume increase. Rainbow trout is one of the most popular fish products.

6 Aquaponic Integration principles

The Report is structured around **aquaponic platforms** where modern finfish production results in marine protein, rainbow trout, as human food and this activity is further linked to both macroalgae and shellfish trophic levels. By combining the finfish production with algae/shellfish the nutrients and wastes from the fish production are actively assimilated by cultured stocks of algae- and is captured by filtering shellfish- held in structures where their growth is monitored and controlled prior harvest.

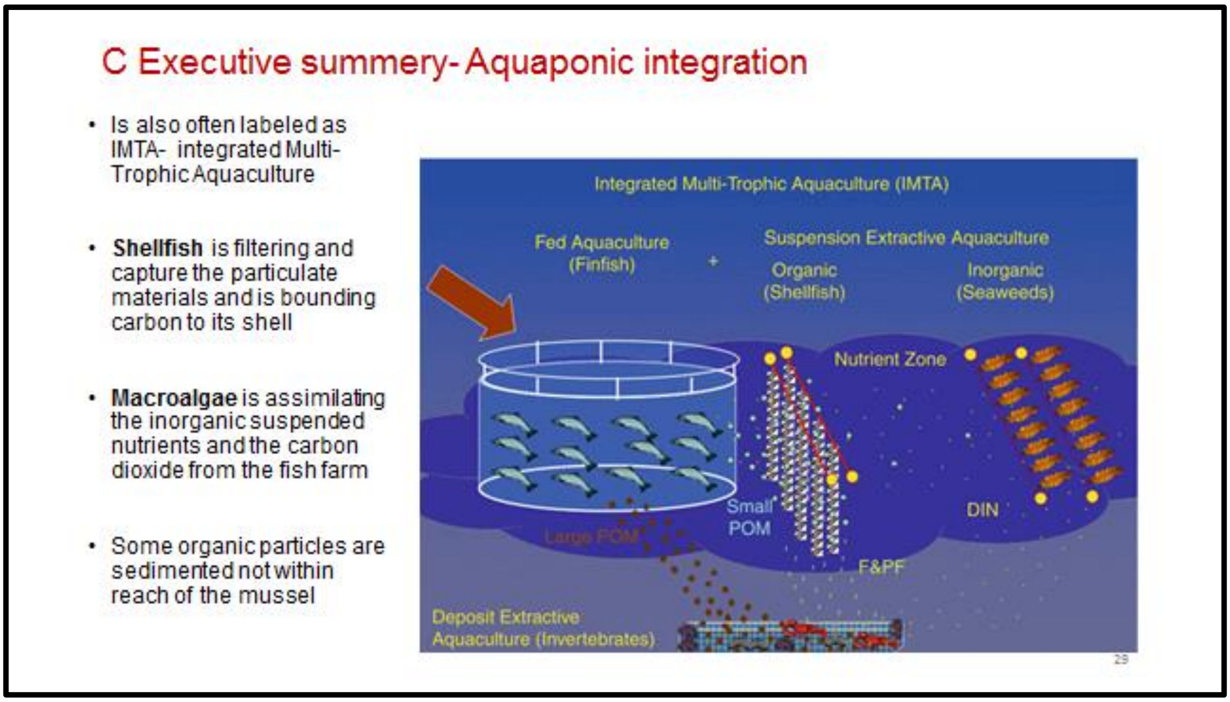


Figure 20 Illustration of aquaponic integration

This may result in algae- and shellfish- products suited as animal feed, human food, sludge and organic wastes from the fish farms can be dewatered and act as fertilizer for the agriculture sector, other cosmetic products and may also act as an energy resource or nutrient source for black soldier flies. Blending waste from both the pelagic fishing sector, fish farming, land animal meat production and other carbohydrate sources could be directed to bio-gas production.

A mechanical water filtration from the enclosed fish biomass may result in approx. 50 grams dry weight (DW) per kg fish produced- annual volume may reach 1 000 tonnes DW or 10 000 tonnes if water content is 90%.

Aquaponic principles

By creating such integration where organic waste and nutrients which normally is released as outflux to the environment will be circulated. These wastes are the result that the fish do digest fish feed, and this result in an assimilation of lipid, protein to the growing fish, whereas faeces and dissolved compounds excreted by the fish do enter the surrounding water column.

By having a planned production scheme, the harvesting of algae and shellfish results in outflux of these captured wastes from the sea.

This may drastically reduce the normal understood impact of modern fish farming activity, where we have selected farming technical platforms that actually allow for maximum outflux of these waste fluxes. By also selecting the best algae and shellfish candidate present in the West Estonia region- we will illustrate new observations of aquaponic net fluxes that may lead to a new decision platform for the West Estonia. Where private stakeholders with public assistance can create a new positive eco-friendly utilization of the potential resources “hidden” in the West Estonia coastline.

Such an integrated circular setup is illustrated for the West Estonia region and our observations are further listed as element for an Action plan for West Estonia Government.

7 West Estonia Water Act- Fish feed development

A Water Act - regulating the flux of N (Nitrogen) and P (Phosphorus) is highly relevant if one is considering the potential of modern fish farming in the region. This has resulted to the development of Baltic feed diets that do scope with such Water Act terms. The fish feed industry in Sweden, Denmark, Finland and Poland is constant looking for new improvements and the latest commercial diet for rainbow trout production is incorporated into this report. The aim is that trout farmers in the region should meet the nutrient requirement from a health growing fish population and at the same time meet the nutrient flux terms.

The illustrated Water Act for West Estonia 2020.

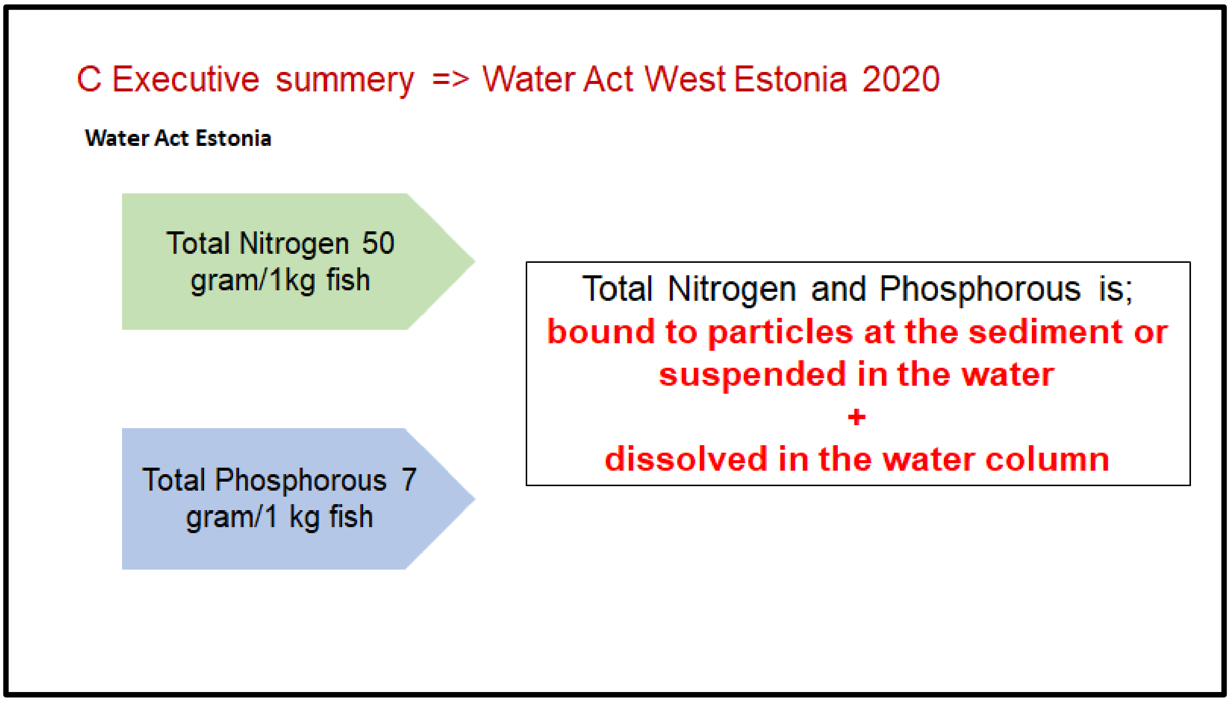


Figure 21. Water Act West Estonia.

8 Modern Baltic fish feed- waste position

However, the latest modern Baltic trout diet, status 2021, allows for a lower Nitrogen and Phosphorous than what is the maximum threshold values per kg fish produced shown above.

Illustration of the Nitrogen and Phosphorus assimilation to rainbow trout, figures are % nutrient bound to the fish flesh as a weight proportion of the live weight of the fish.

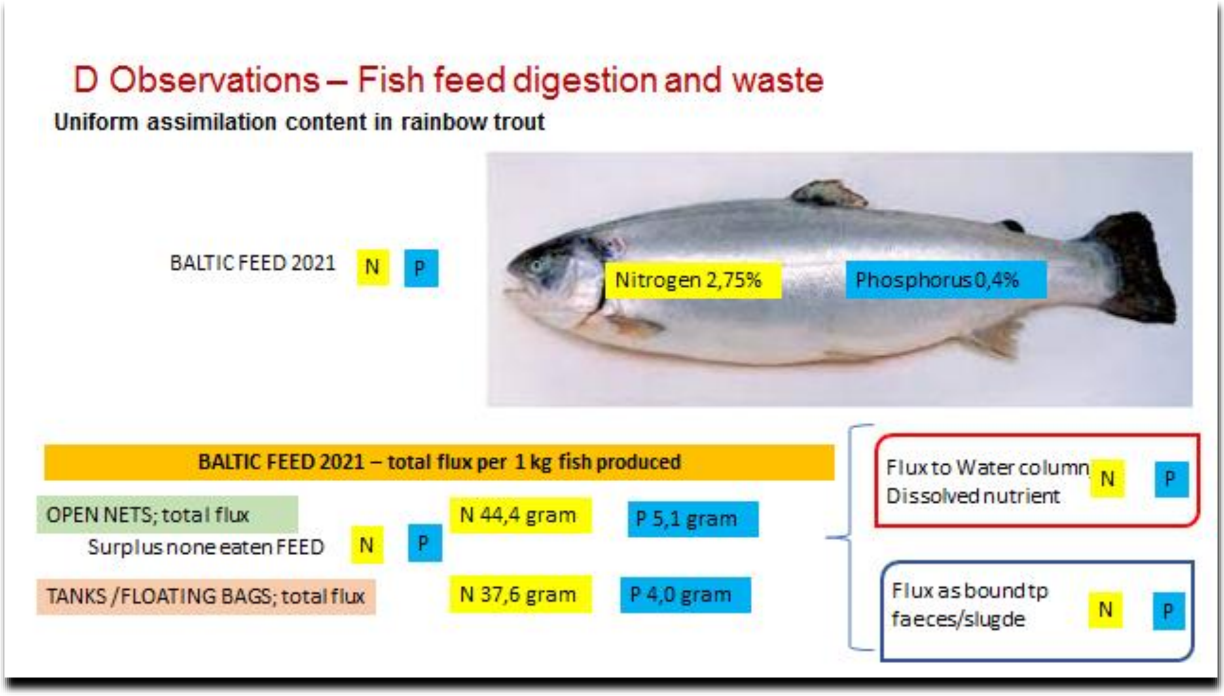


Figure 22. Assimilation of nutrient to the fish wet weight.

Fish feed Baltic 2021

A modern Baltic fish feed may have the following nutrition building composition;

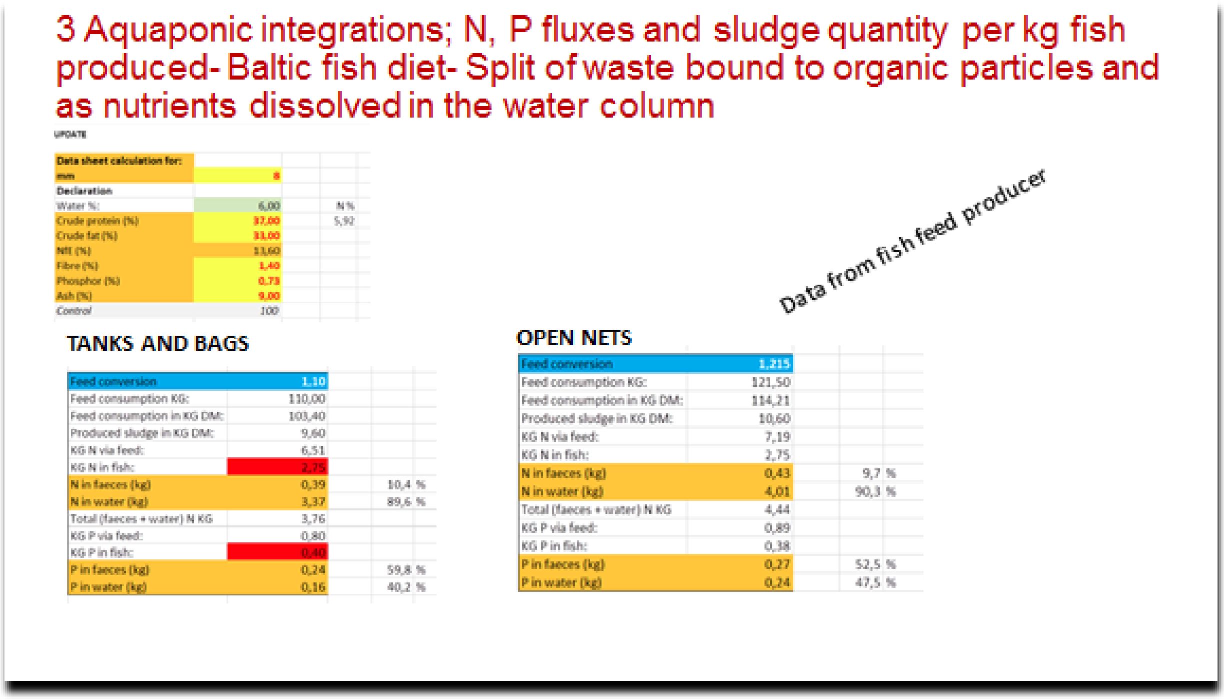


Figure 31. An illustration of one of the latest Baltic fish feed.

Explanations;

- There is different volume of sludge to the environment considering Open nets and two other enclosed platforms. There is also different quantity and also the % split of nutrient bound to particles and dissolved to the water column.
- The only difference we have setup is that feed conversion ratio (FCR) for Open nets is set at 1.215 and for enclosed platforms FCR is set at 1.100.
- Other fish feed compositions have different performances.

9 Waste fluxes with and without aquaponic integration

Illustrated land based and floating platform.

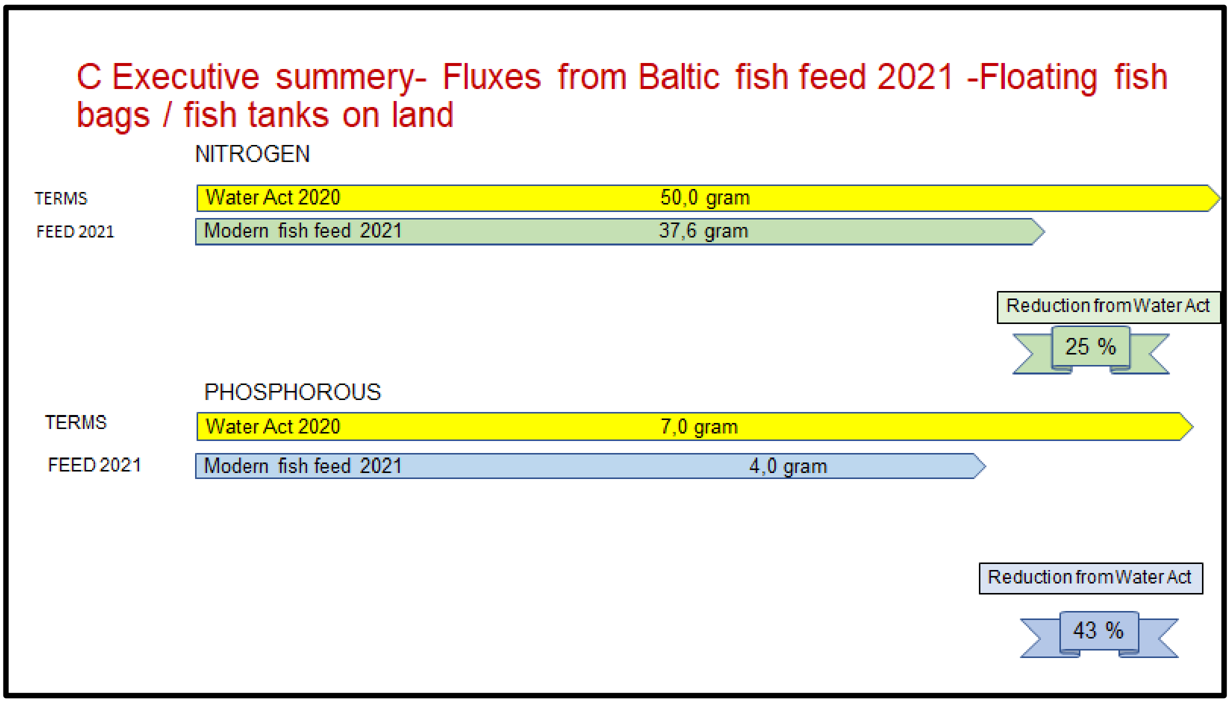


Figure 23. Land based and floating bags concept fluxes.

With the said reduced / avoided overfeeding and slightly higher survival the two - 2 - technical enclosed platforms (tanks on-land and floating bags) already represent an improved position related to fluxes- 25% lower for N and 43% reduction of Phosphorous, see Figure 23. Our baseline is here illustrated as if 1.10 kg fish feed is required to produce 1.00 kg fish. These % reduced fluxes could allow farmers to produce similar increased % of biomass compared to traditional Open net concept. However, as of today these platforms are not in use in the Baltic Sea for larger rainbow trout.

<u>For Open net platform we have</u>

Feed status 2021 is showing Nitrogen fluxes of 11% and for Phosphorous flux reduction of 27% benchmark with the Water Act guideline. Here we are considering that 1.21 kg fish feed is required to produce 1 kg fish live weight.

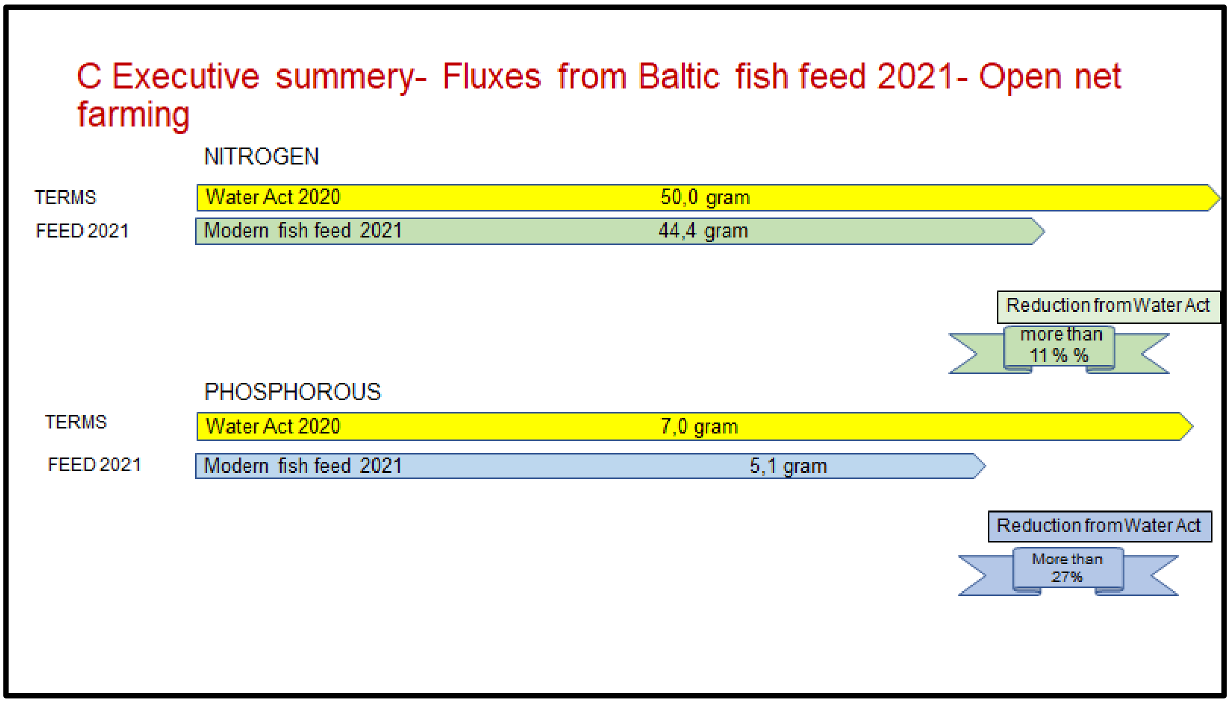
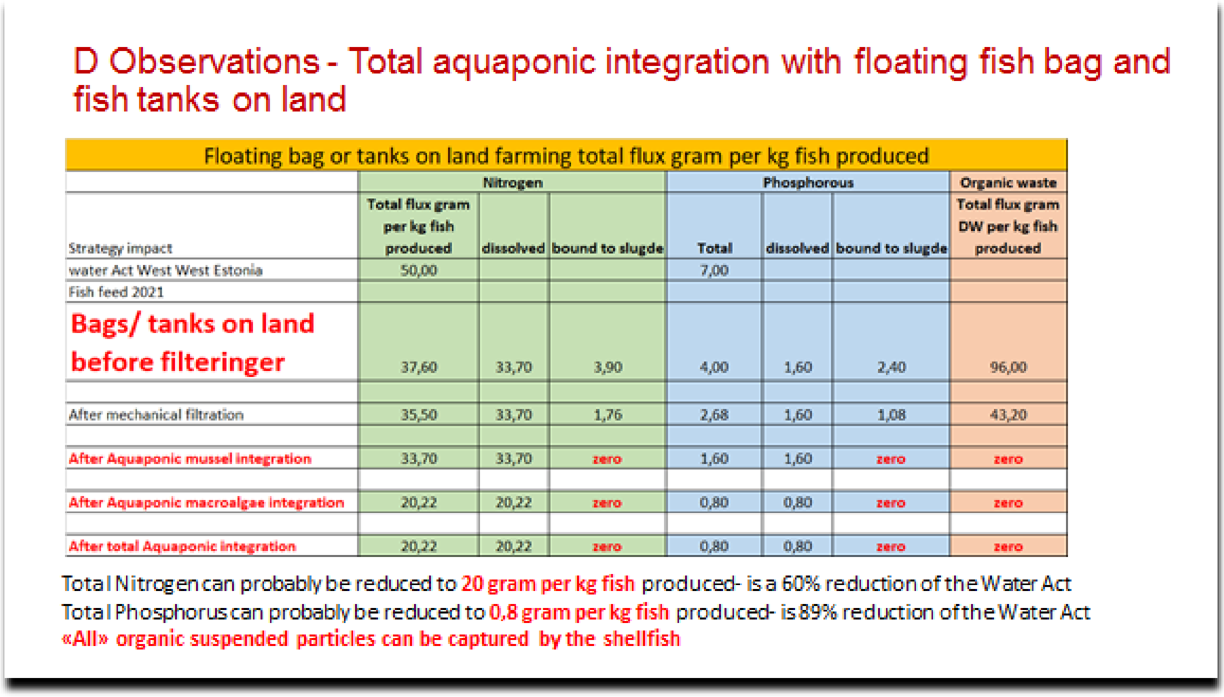


Figure 24. Illustrations of waste fluxes for Open net concept.

Details of the waste and dissolved nutrient mass balance for land-based fish tanks and floating bag concept.

The figure below shows the split of waste as dissolved and bounded fraction for both Nitrogen and Phosphorus.


D Observations - Total aquaponic integration with floating fish bag and fish tanks on land

Floating bag or tanks on land farming total flux gram per kg fish produced							
	Nitrogen			Phosphorous			Organic waste
Strategy impact	Total flux gram per kg fish produced	dissolved	bound to slugde	Total	dissolved	bound to slugde	Total flux gram DW per kg fish produced
water Act West West Estonia	50,00			7,00			
Fish feed 2021							
Bags/ tanks on land before filteringer	37,60	33,70	3,90	4,00	1,60	2,40	96,00
After mechanical filtration	35,50	33,70	1,76	2,68	1,60	1,08	43,20
After Aquaponic mussel integration	33,70	33,70	zero	1,60	1,60	zero	zero
After Aquaponic macroalgae integration	20,22	20,22	zero	0,80	0,80	zero	zero
After total Aquaponic integration	20,22	20,22	zero	0,80	0,80	zero	zero

Total Nitrogen can probably be reduced to 20 gram per kg fish produced- is a 60% reduction of the Water Act
Total Phosphorus can probably be reduced to 0,8 gram per kg fish produced- is 89% reduction of the Water Act
«All» organic suspended particles can be captured by the shellfish

Figure 25. Detail fluxes for enclosed farming platforms.

<u>Short explanation</u>

- The total Nitrogen flux is for bags and fish tanks that there is approx. 90% dissolved into the water column and 10% bound to particles. This indicates that mechanical filtration and or mussel capture filtration can act as the major source for reduction of N fluxes.

- For P there is approx. 40%/60% split - filtration (mechanical or by mussel) may here have a lower impact compare to N “filtration” results.
- There is approx. 100 grams DW sludge formed for every 1.0 kg rainbow trout from these enclosed farming setup – NB! this sludge is higher for Open net farming.
- After mussel integration there is zero organic waste to sea.
- After mussel integration N fluxes is reduced to approx. 34 grams and P to 1,6 grams.
- After macroalgae integration N can reach level of 20 grams and P 0.8 grams per kg fish produced.

Illustration for the open nets platform.

D Observations - Macroalgae + mussel Offshore cultivation total waste flux from Open net farming

Open net farming total flux gram per kg fish produced							
	Nitrogen			Phosphorous			Organic waste
Strategy impact	Total flux gram per kg fish produced	dissolved	bound to slugde	Total	dissolved	bound to slugde	Total flux gram DW per kg fish produced
water Act West West Estonia	50,00			7,00			
Fish feed 2021							
Open nets none filteringer	44,40	40,10	4,30	5,10	2,70	2,40	96,00
After mechanical filtration	44,40	40,10	4,30	5,10	2,70	2,40	96,00
Ocean cultivation mussel	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Ocean cultivation macroalgae	TBD	TBD	TBD	TBD	TBD	TBD	TBD
After total Ocean cultivation	TBD	TBD	TBD	TBD	TBD	TBD	TBD

Total Nitrogen will reach less than 44 gram per kg fish produced (11% reduction of Water Act), is depended upon which Offshore cultivation zones to be selected.
Total Phosphorus will reach less than 5,1 gram (27% of Water Act) per kg fish produced- is depended upon which Offshore cultivation zones to be selected. Organic suspended particles can be captured by Offshore cultivation arrangements of shellfish- TBD.

Figure 26. Fluxes for Open net farming.

Short explanation

- Therefore, the net fluxes of N and P is approx. 44 grams and 5.1 grams.
- Therefore, the total organic particles flux is 96 grams DW per 1.00 kg fish produced.

10 Fish farming planning

Our base line production parameters is listed below.

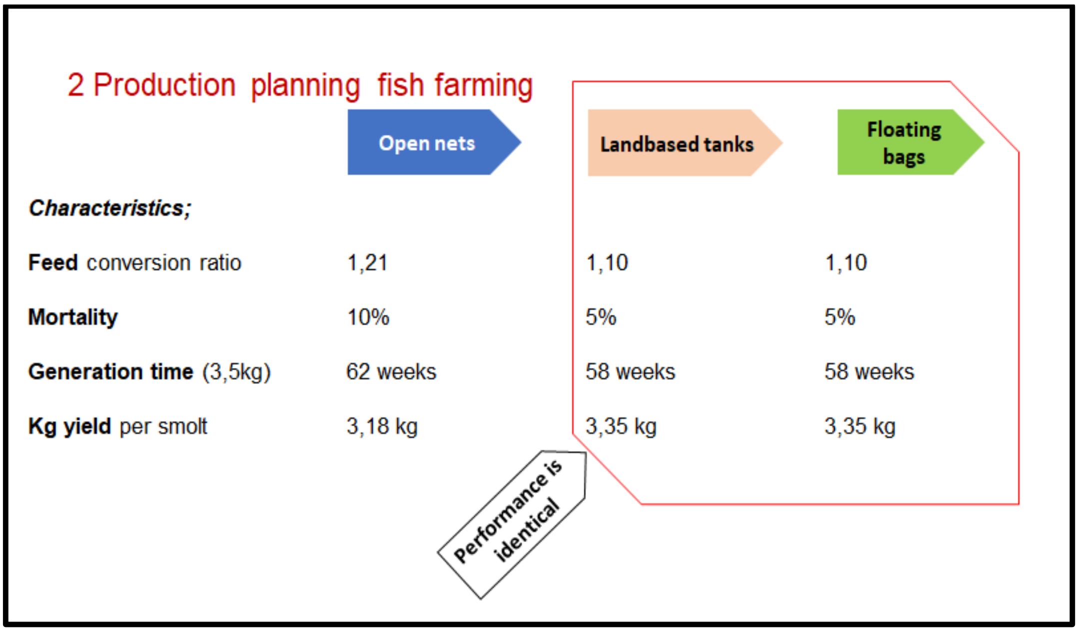


Figure 27. Feed usage, survival, generation time.

<u>Comments</u>

- These feed conversion ratios showing how much fish feed is required to produce 1 kg live fish weight shows that approx. +10% higher feed volume is spent on Open net farming compared to more controlled enclosed setup as fish tanks on-land or floating fish bags.
- This results in an extra nutrient flux to the environment.
- The other elements is that in this Report we have estimated that Open nets will have twice as high mortality compared to the other more controlled platforms (10% vs 5%) - this also represents an additional nutrient fluxes as this lost biomass also have digested and combusted an extra feed volume by this additional dead biomass with a result of some quantity of N and P as faeces/sludge and also as dissolved nutrients to the water column.
- All these factors is incorporated into the Report.

These elements is also illustrated below:

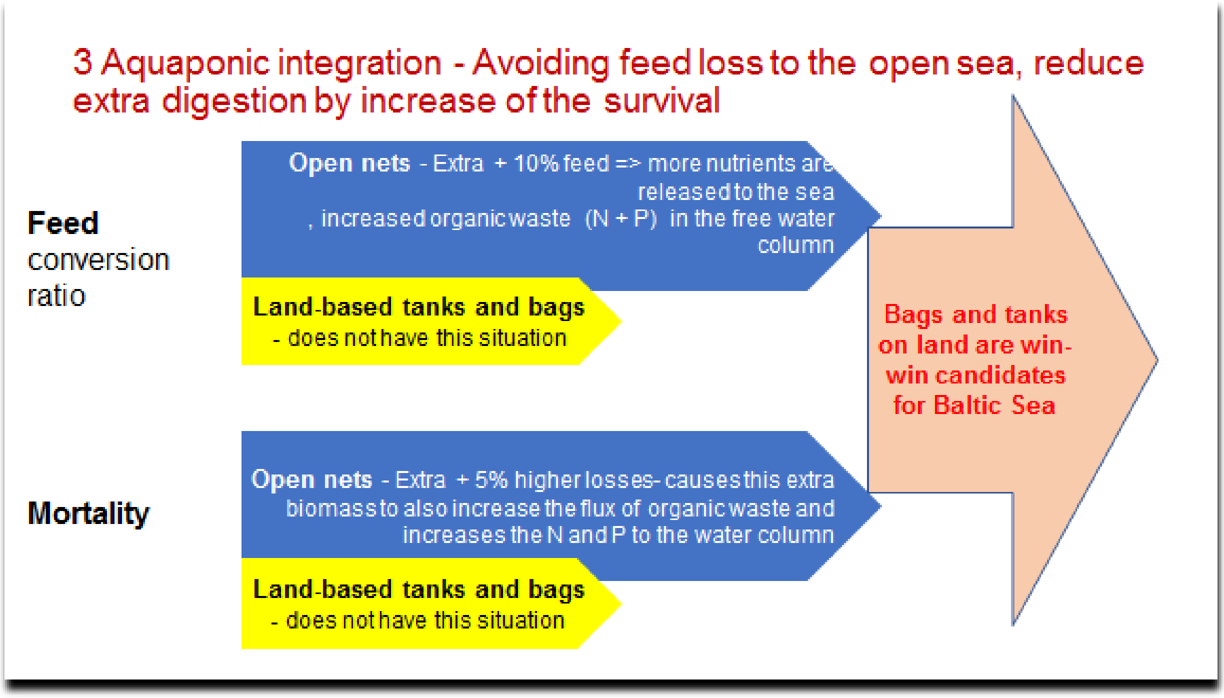


Figure 28. Surplus waste fluxed by Open net farming.

2 Production planning fish farming

The potential of fishfarming production in West Estonia is very promissing, however as with other regions one must consider the pro and con for such activity and also pay attention to potential risk factors:

As for any Open net strategy

- we predict a farming time of approx. 62 weeks for each fish group released
- where the live swimming weight is 3,5 kg
- with 10% accumulated loss
- the winter temperature will restrict the entry of smolts year round
- Natural smolt entry to sea is 1 April- 1 Oct- this will expand the whole generation period by 7 months- total generation period is close to 21 months
- A 3 months fallow period could result that re-stocking takes place every 75 weeks per site

Figure 29. Generation time, accumulated loss, harvest weight.

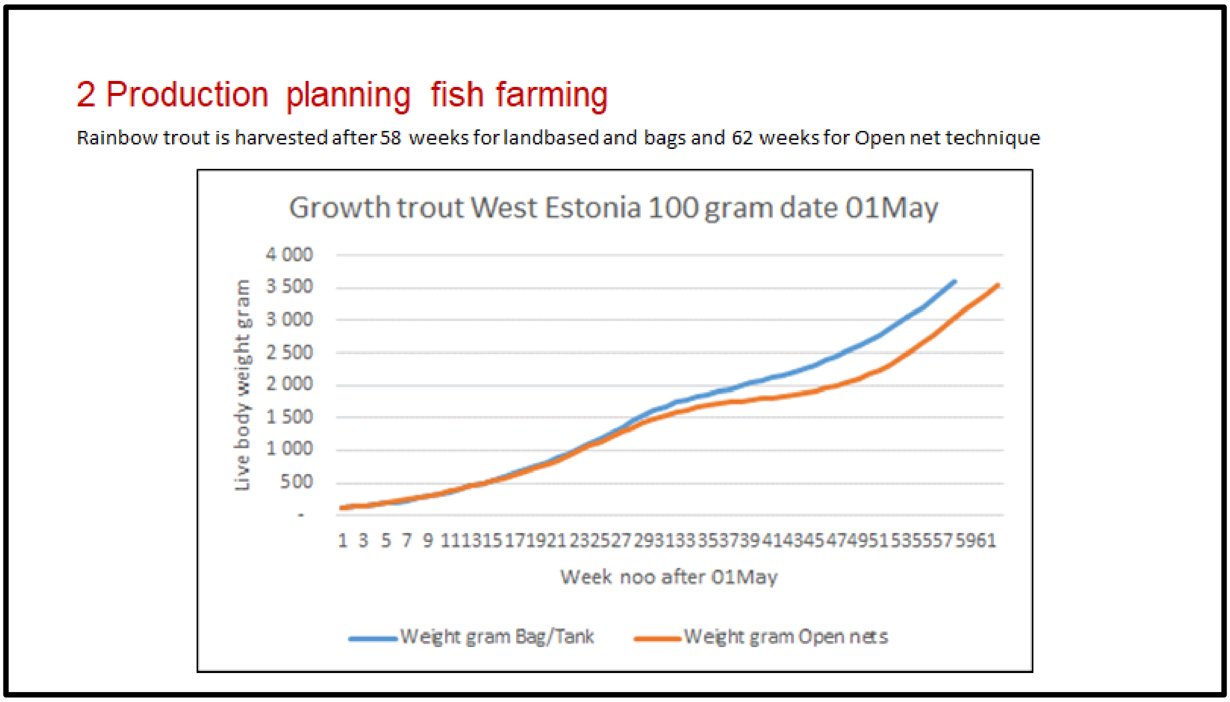


Figure 30. Growth performance Open nets versus Floating bags/tanks on land.

<u>Current fish farming activity in Baltic Sea</u>

The situation among fish farmers, especially the one operated in Denmark, Sweden and Finland, with Open net technique, is that their permits are under pressure and the total farmed volume of approx. 35 000 MT trout is consolidated among a few players. It is also a fact that some do practice Ocean cultivation of blue mussel (Sweden, Denmark, Finland), but to our knowledge basically none have yet strategically changed their Open net technology. Alternative farming platforms are illustrated in this report to secure a long-term predictable farming activity where public officials easy can monitor and take active part of new farming techniques which are special designed and adapted to the listed eutrophication conditions of the Baltic Sea.

The foundation for such a circular utilization of marine resources is looked upon where an alternative modern setup of salmonid production in the region is the baseline. This report is not specific focusing on modern RAS facilities, Recirculation Aquaculture System, as they are very costly, technical and we consider that an entry of other modern fish farming alternatives is better suited. However, there is a fact that the high-tech RAS I and RAS II setup may also reduce the waste fluxes at a higher level than the straightforward mechanical water filtration set up in this report.

11 Fish farming platforms covered in this report

Open net farm general information

All nutrients and waste from the Open net farming setup do enter the water column.

a) However, with modern fish feed these fluxes are reduced.
b) The Open net platform is the dominant strategy worldwide for salmonid production.
c) It is very effective.
d) Represent a low capex entry cost.
e) The faming technique and protocols is highly improved over many years.
f) Requires hardly any land-based setup except for harvest and processing.
g) Is a very low area demanding platform with a fantastic high productivity.

Figure 32. Illustration; Open net farm.

- The overall salmon production dominated by Norway, Scotland, Chile and North America is by use of Open net technology which is characterized by
  - A low cost setup.
  - Very functional and easy to operate, but it is also a very low utilization of the aquaponic potential. All wastes and nutrients are entering the open sea where they are heavily diluted.
  - It is difficult to collect the large suspended particle fraction from the open nets. The excess waste from the fish production will settle to the seabed and will increase the eutrophication and drive the oxygen combusting in a negative direction.
  - However, any increased amount of land animal meat production will also result in extra fluxes both from the agriculture sector by producing the animal feed itself (fertilizer, transport), and by the animal digestion of the feed.

Illustration of the life cycle of rainbow trout.

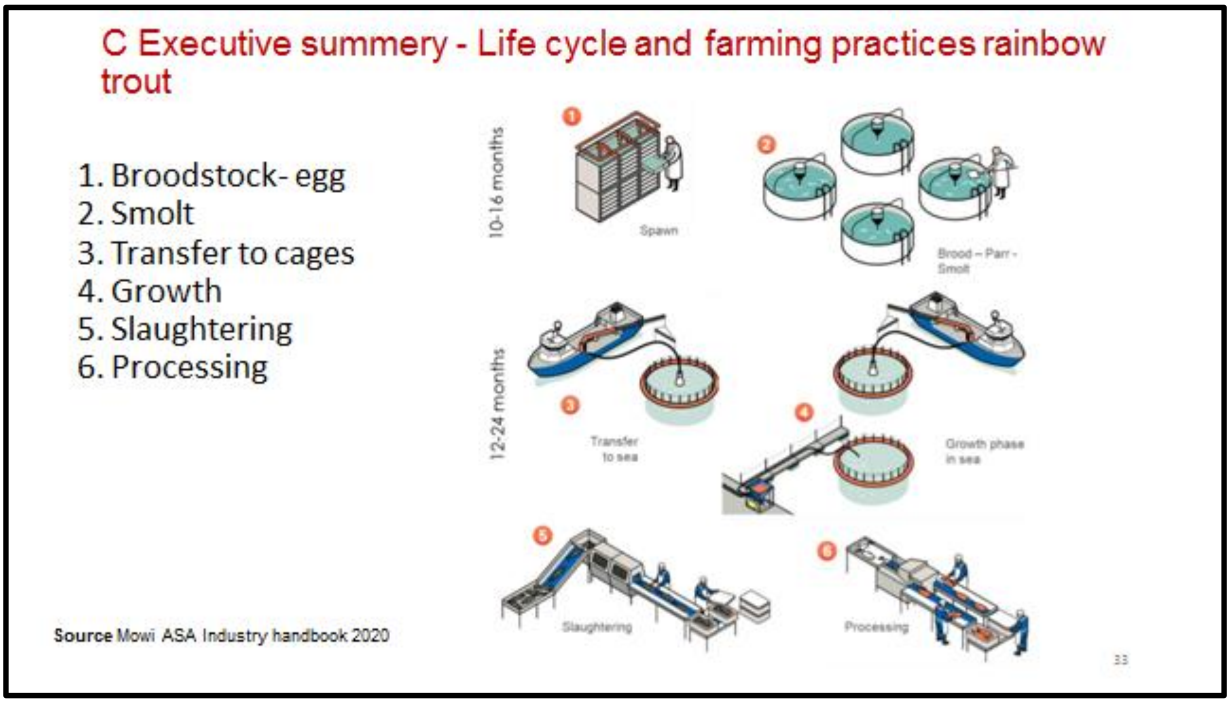


Figure 33. Life cycle rainbow trout.

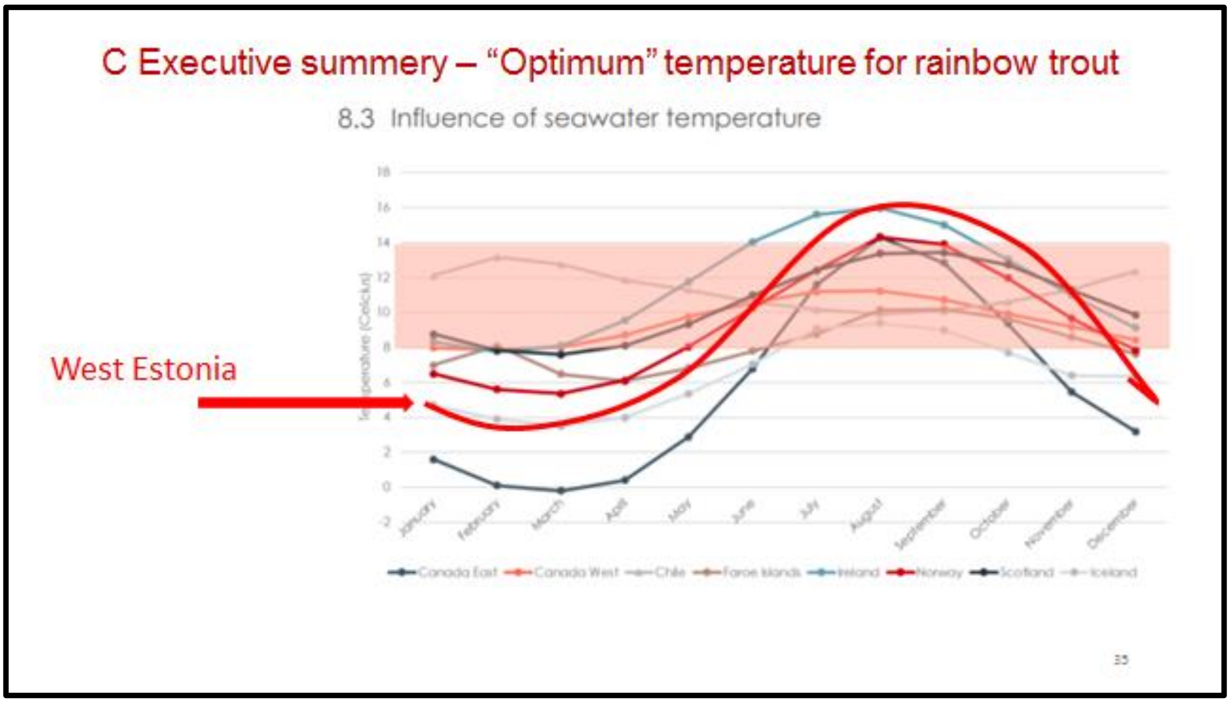


Figure 34. Temperature profile West Estonia.

Comments: the temperature profile in winter time may be lower than 3.5 degrees, and in summer time under very good weather conditions the surface layer may reach higher profile than the illustrated 16 degrees. Swedish/Finnish trout farmer in the Northern Baltic regions have farmed trout for approx. 40 years, also in freshwater lakes. In Southern Norway trout is also farmed for a long period- there exists farming protocols that is well adapted to the conditions of West Estonia.

Drifting ice in the springtime and severe bad weather at exposed sites will cause precaution.

Floating fish bag technique- illustration

Illustration below, Figure 35, is from one the 4x different enclosed systems commercially available in Norway; manufacturer www.Ecomerden.no

The drawings illustrated the arrangement of the floating surface collar ring where the bag is attached. Inlet pipes, generator and pumping facilities are integrated into the collar. This unit is of large size, 30 000 m^3 with a diameter of 40 m and a depth of 20 m.

Smaller arrangements with smaller volume sizes special adapter for the shallow exposed West Estonia coastline must be considered. In our report we have scale the dimensions down to cover a bag unit of 6 200 m^3, being 10 m deep and a diameter of 24 meter. We will lead the outcoming wastewater with the organic materials and dissolved nutrient by an enclosed pipe loop to a mechanical filtration station. Here a high proportion of the suspended particles is withdrawn from the outlet water, however the dissolved nutrients remain in the water passing through this mechanical filter.

The remaining micro suspended particles will also be remained in the outflux water from the fish bags and can act as mussel food. The dissolved nutrient will act as macroalgae food for its photosynthesis.

The water volume is not pumped but is pushed into the aquaponic units, resulting in approx. ⅙ of the energy requirement compared to land-based fish farming.

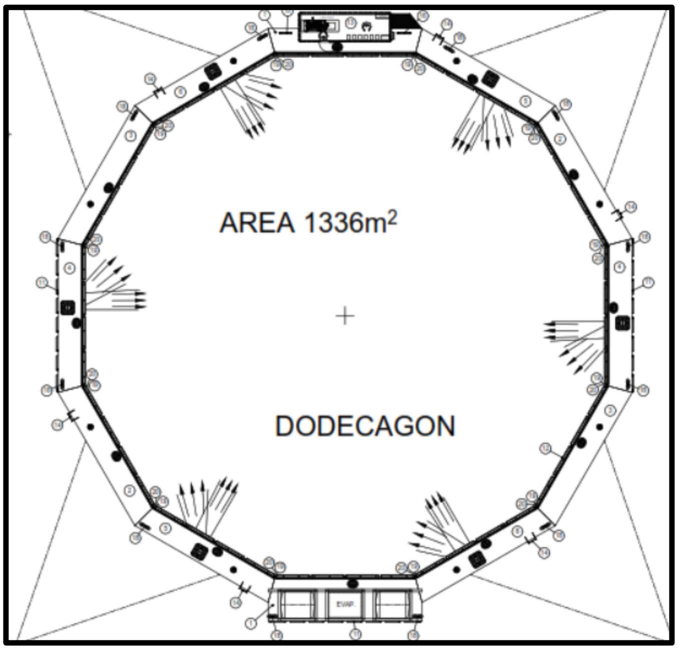


Figure 35. Illustration of the bag concept.

Illustration of the combination of one floating fish bags with traditional Open net platform Norway;

Figure 36. Floating fish bag in combination with traditional Open nets.

Comments:

- One large semi-enclosed floating bag with salmon production in Norway is integrated with 5x traditional open net cages.
- These units may hold approx. 100 000 – 200 000 Atlantic salmon each, at harvest their biomass is 500 MT up to 1 000 MT per unit.
- There are in total approx. 45x such enclosed floating bags in operation (24/7) in Norway today.
- Some of them are smaller, see Figure 37 below, operated at R&D stations providing trials for the industry, fish vaccine and for fish feed manufacturers.
- In our feasibility study for West Estonia we have drastic reduced the number of fish per unit, but is having a density of approx. 35 kg/m^3 enclosed volume at maximum - resulting in approx. a total biomass prior harvest of 200-230 tonnes per unit, bag depth of 10 m.

Figure 37. Various floating bags concepts.

Land based fish farming

We have included large fish tanks on-land to estimate the production, feed volume and waste fluxes for location being approved with such a farming concept.

The fish will digest and produce waste regardless of which tank farm they are kept in; however, our study is large tanks 4.5 m water height and diameter of 22 meter, 2 200 m^3 each. With a density of approx. 35 kg trout/m^3, the productivity per fish tank is in the range of 90 tonnes live weight per year. This biomass produced require then a fish feed volume and will produce its wastes entering the outflux water to the mechanical filter station prior entering the sea. In an enclosed aquaponic integration this flux is entering mussel and/or macroalgae units.

There is a vast number of fish tanks configurations - below are some illustrations.

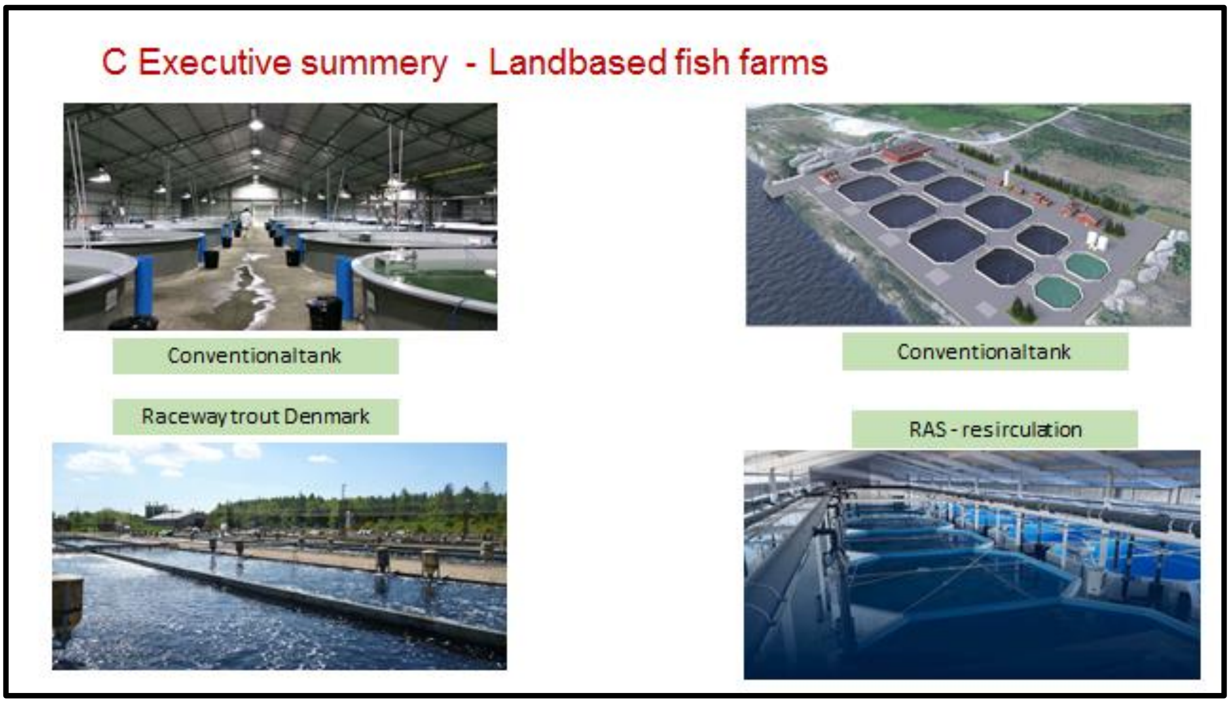


Figure 38. Various fish tanks on land.

This report illustrates 2x different situations where fish production is having an aquaponic circular structure. A third version is where ambient natural concentrations of nutrient and organic materials present in the West coastal zone, without fish farming activity being integrated, can be assimilated by an **ocean cultivation** setup based upon a human controlled planting of algae seedling and mussel seedling at dedicated areas- this is labelled as Ocean harvest in this report.

<u>The 3x methods are listed below;</u>

For detailed modelling of mussel aquaponic see appendices.

1. **Method A** Use of **semi enclosed floating large "bag"**/units on the sea surface **with** physical aquaponic units for cultivation of shellfish and macroalgae in an integrated setup.

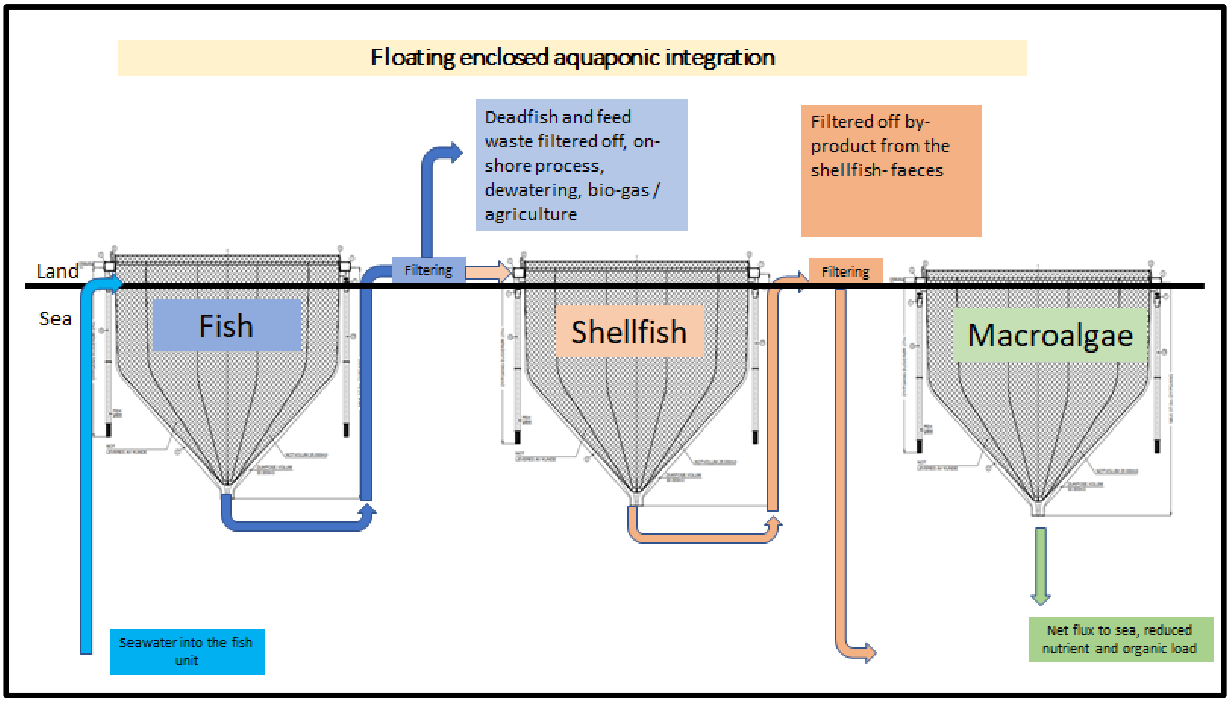


Figure 39. Integration of fish tanks and aquaponic units.

2. **Method B** onshore farming with **traditional fish tanks** with integration of aquaponic units for cultivation of shellfish and macroalgae in an integrated setup.

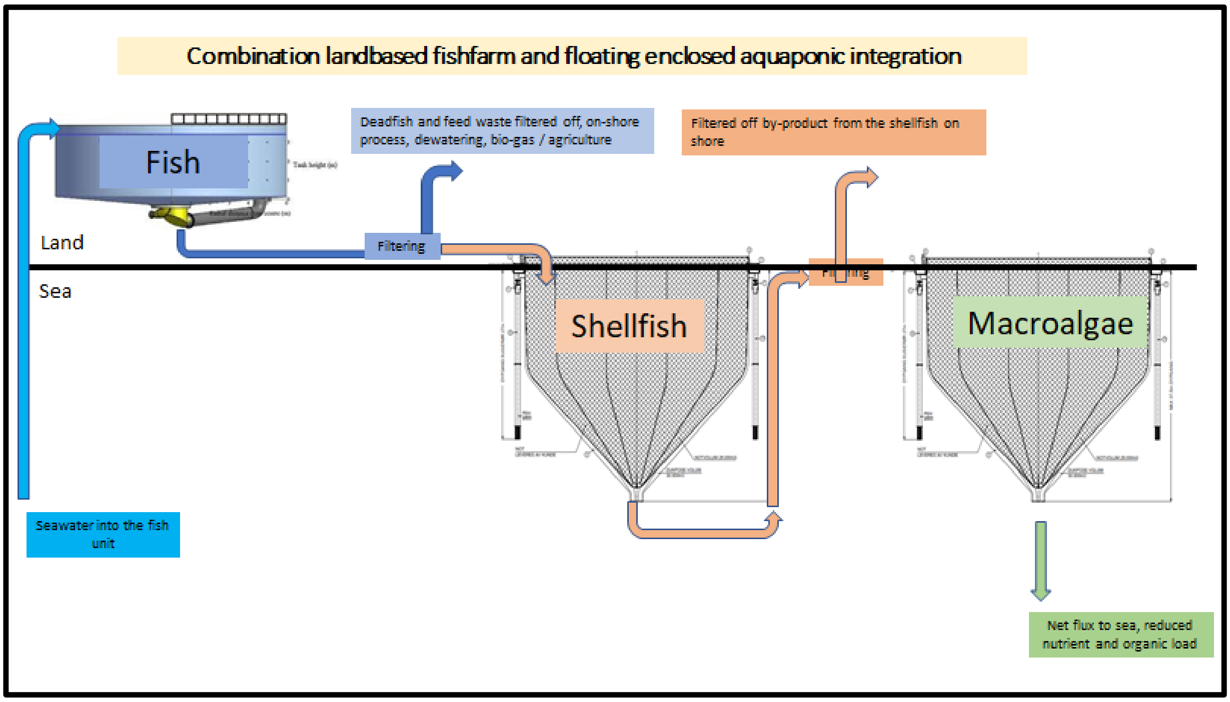


Figure 40. Land based fish tanks with floating aquaponic units.

Method B Land based fish farm with aquaponic structure

- Here the waste from land-based fish tanks is passing through integrated floating enclosed bags for macroalgae and mussel production.
- The bulk of the fish waste can be filtered off by use of mechanical filters prior entering the aquaponic arrangements.

Method C Ocean cultivation of algae and shellfish not including fish farming activity.

- Macroalgal farms are assimilating ambient nutrients and mussel farms are filtering out natural particles (mostly phytoplankton) and hence nutrients.

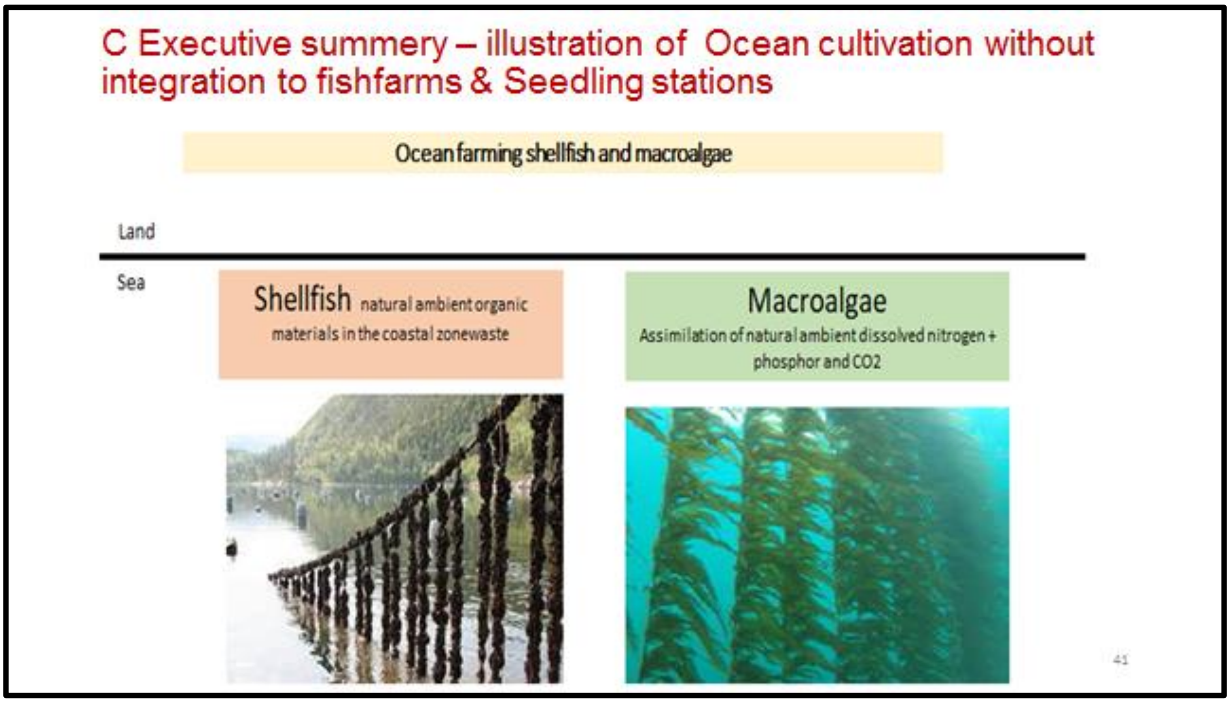


Figure 41. Illustration of the cultivation and harvest of shellfish and algae.

<u>For the aquaponic integration with both algae and mussel one need a starting cultivation of mussel.</u>

- This is arranged by using traditional open cultivation techniques in the near shore zone early in the spring (late May – early June) where free-swimming juvenile mussels, veliger, are attached to trawler nets and other nylon arrangements.
- Often handing in vertical rope structures from the surface.
- After settling the mussel will grow and at the age of 9 months old they are having a filtering capacity which is well suited for capturing suspended waste particles inside floating mussel bags close to the land based or floating fish units.

12 Integration of shellfish to our fish units

The seasonal filtering potential of mussel in West Estonia.

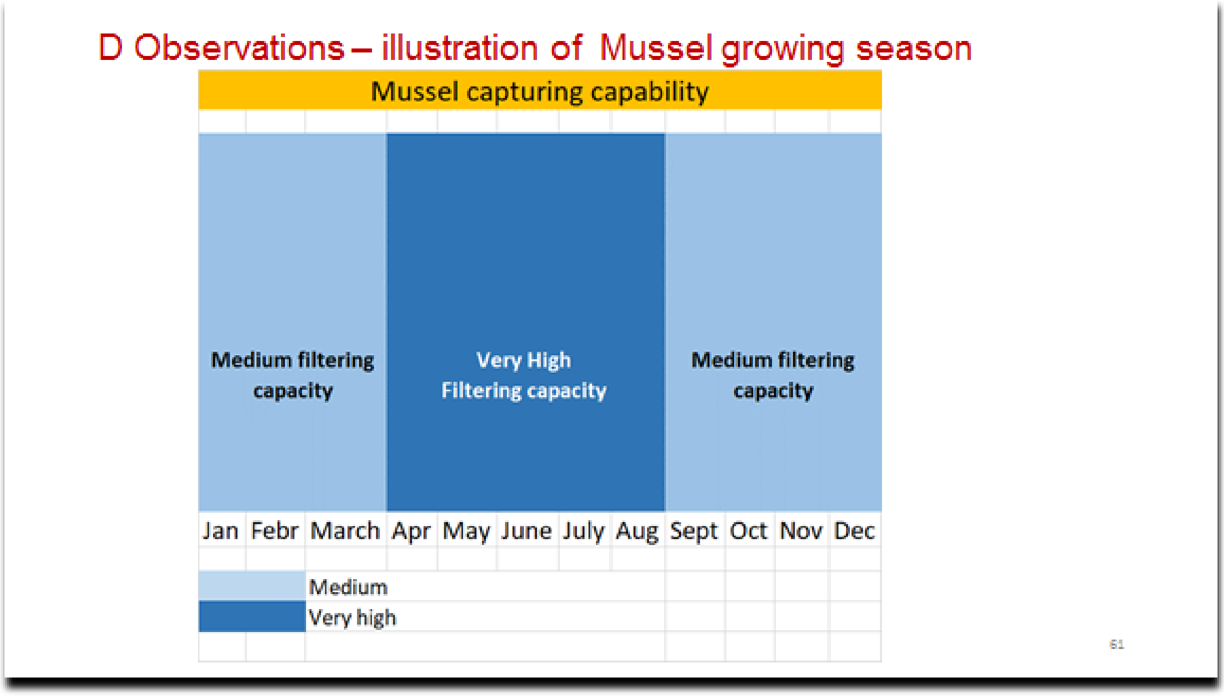


Figure 42. Seasonal variability in the filtering performance of mussels.

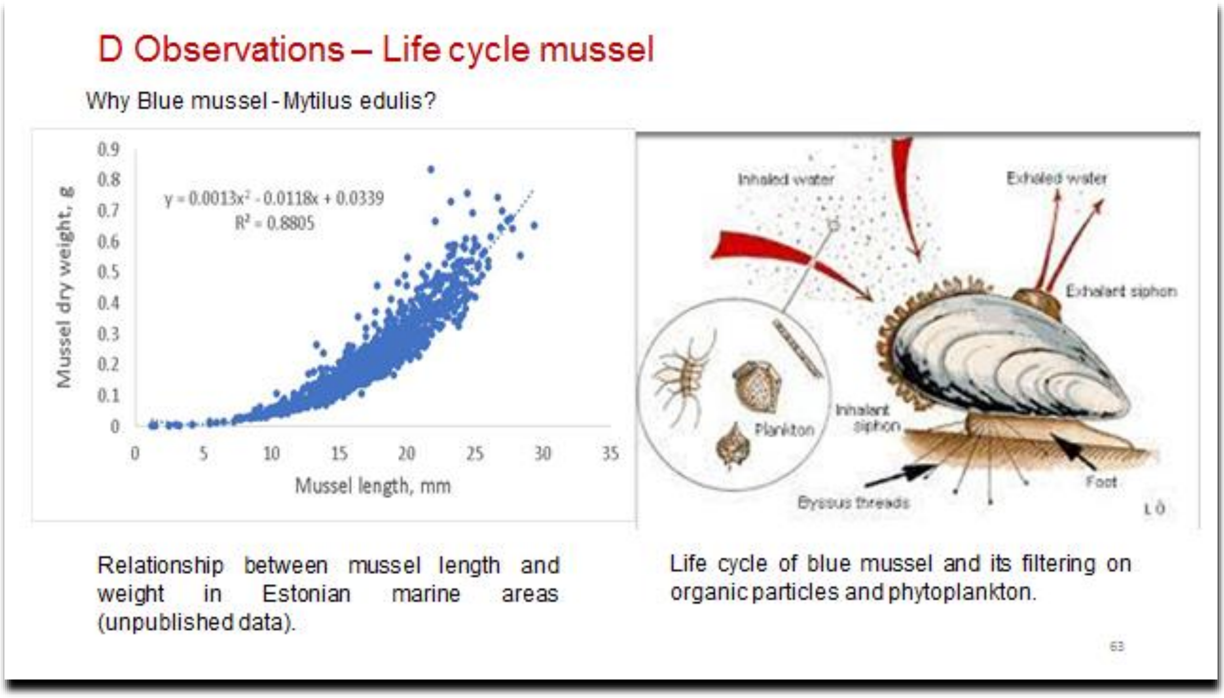


Figure 43. Life cycle of the blue mussel and their allometric relationships in the West Estonian area.

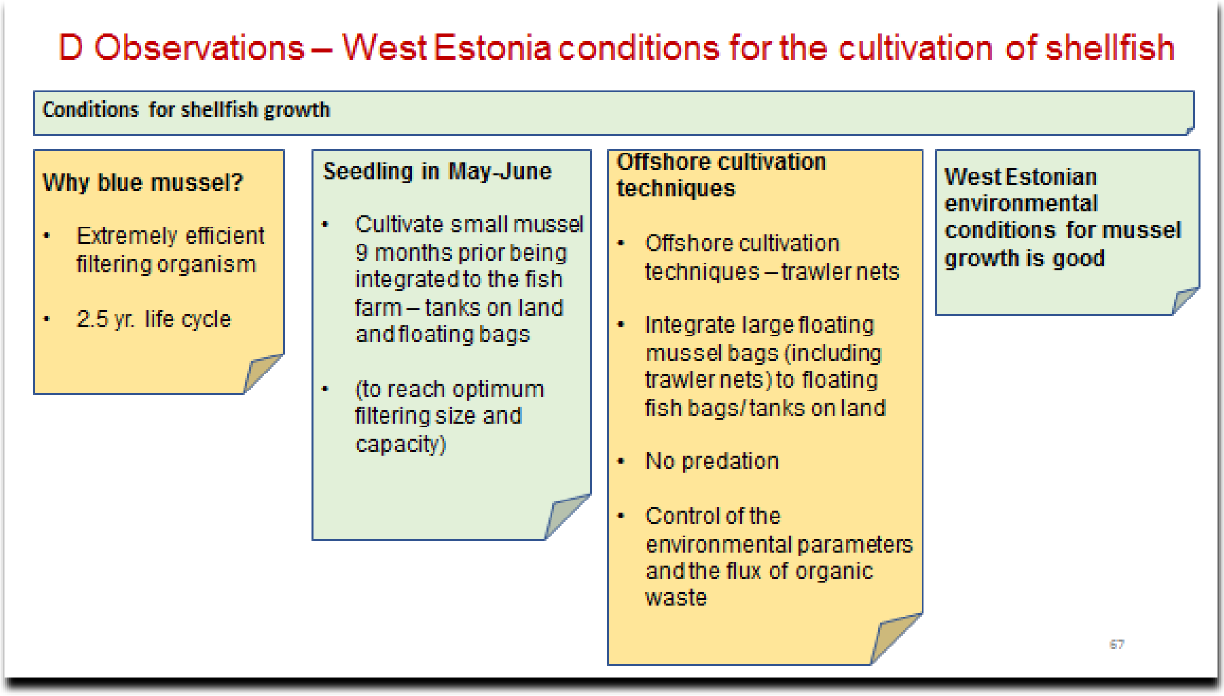


Figure 44. The conditions for mussel growth in West Estonia.

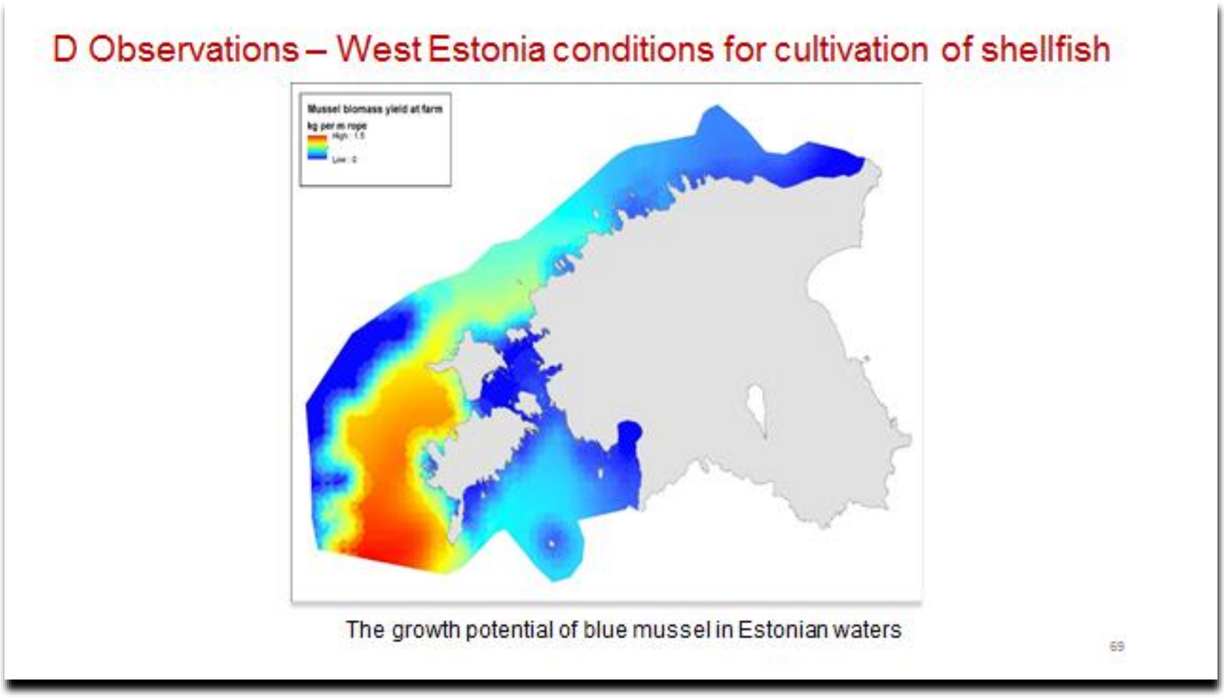
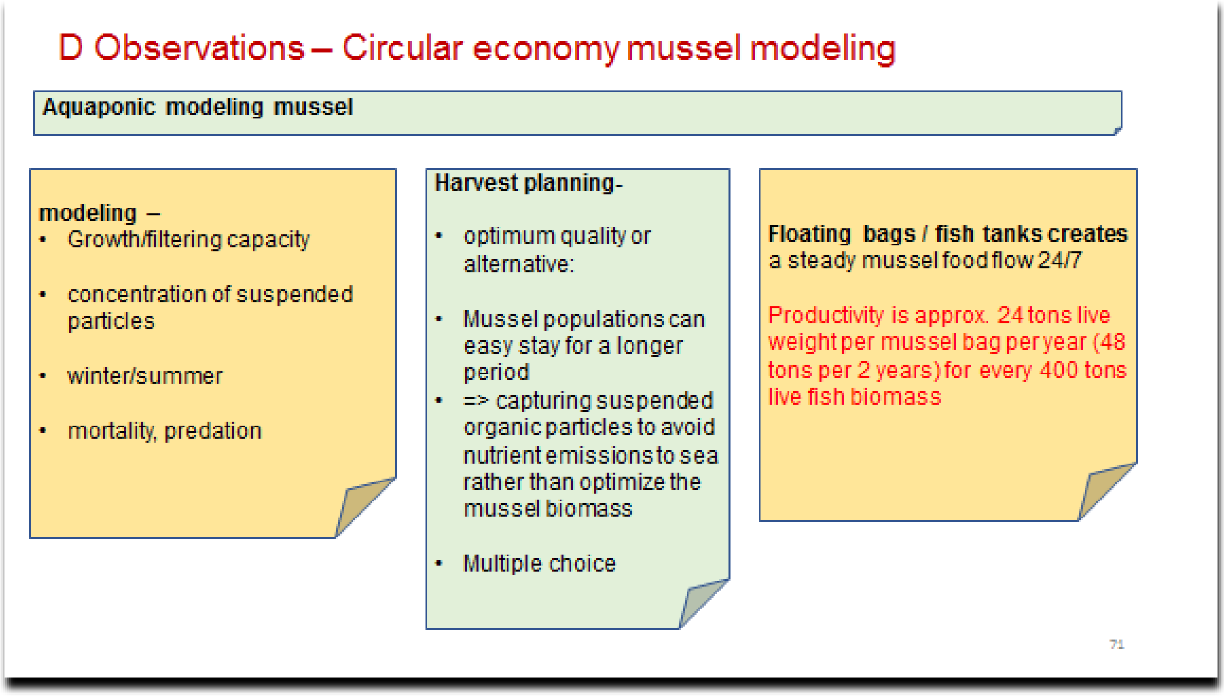


Figure 45. Optimum coastal zone for mussel growth indicated with red and yellow colour.



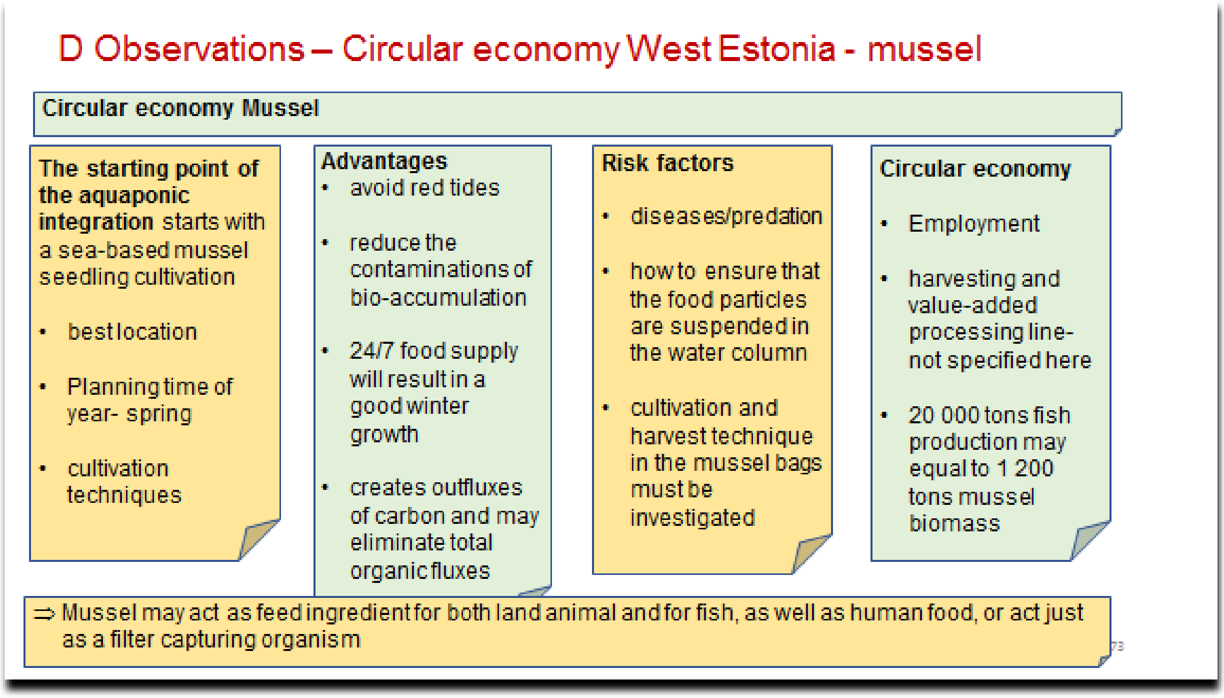


Figure 46. Circular economy of mussel aquaponic.

Offshore cultivation of mussel

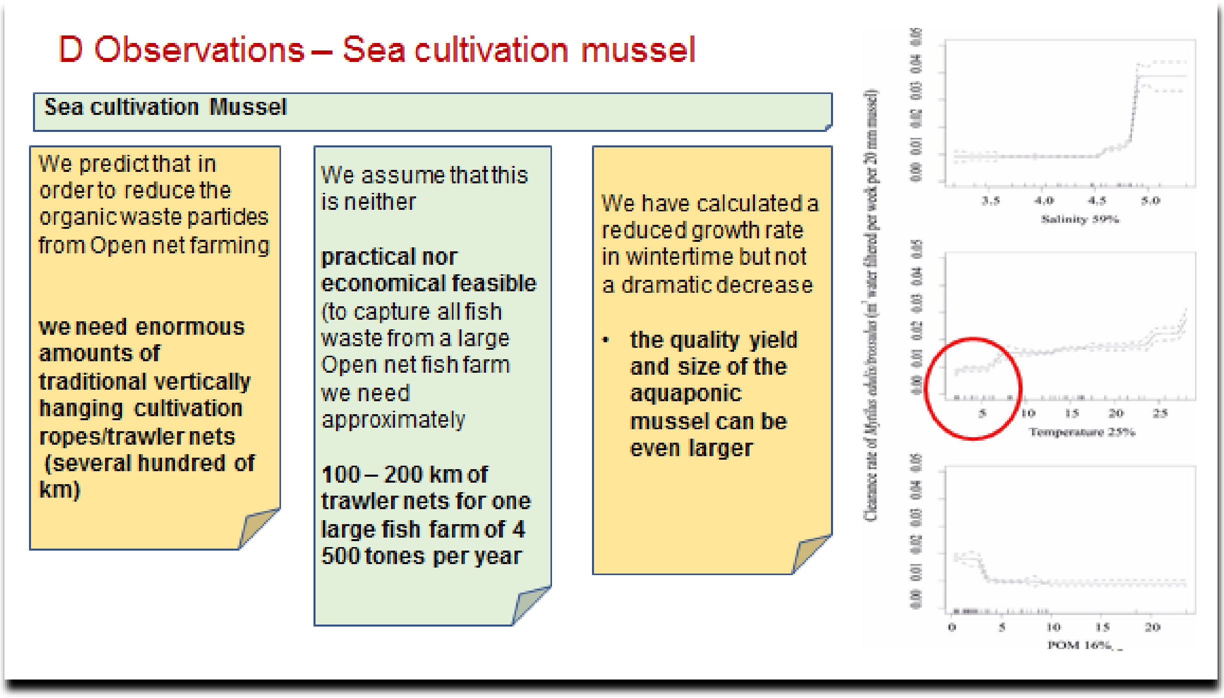


Figure 47. Offshore cultivation of mussel to compensate traditional fish farm effluents.

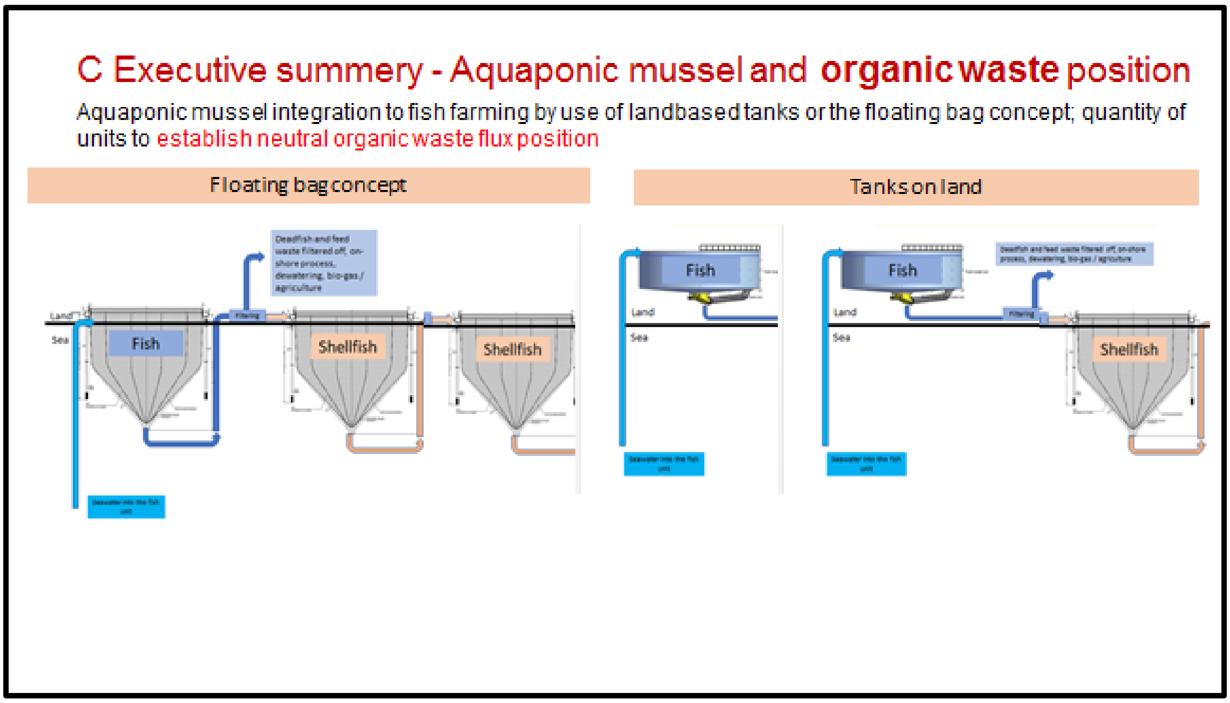


Figure 48. Illustration of the setting up of shellfish aquaponic system.

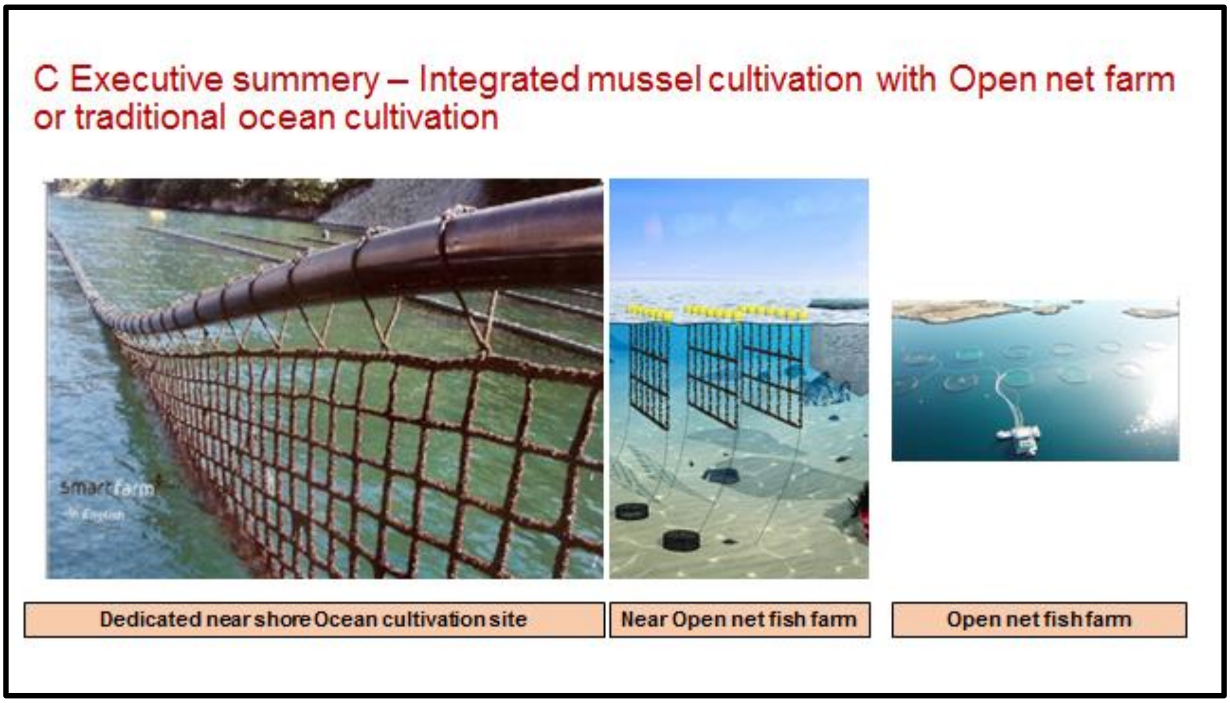


Figure 49. Illustration of offshore cultivation.

13 Integration of macroalgae to our fish units

<u>The philosophy is very much similar as the integration of shellfish; however, there is a big difference in applicability.</u>

- As the algae are having a seasonal limited growth period every year caused by colder sea water in late autumn / winter and absent of sunlight - the macroalgae will naturally become weaker, will degrade and be absent until early spring.
- Then the new growth season starts.
- This will also take place inside our floating algae bags which in the same period will not assimilate the dissolved nutrients.
- The result is that aquaponic algae setup in West Estonia and elsewhere will only have a positive contribution as long as there is enough sunlight and combined with good concentrations of nutrients in the free water column.

This is illustrated.

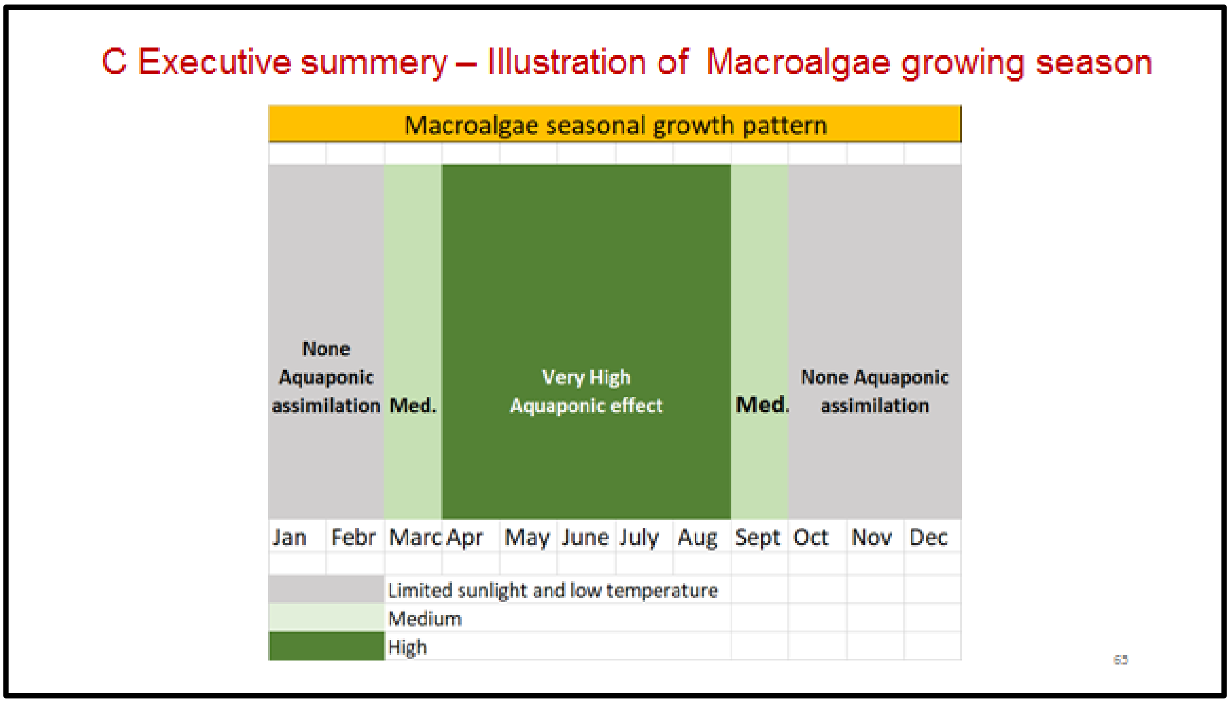


Figure 50. Macroalgae performance.

Therefore, we need early in the spring population of algae that is produced at a land based culturing stations. This will result in a fast growth of early spring biomass of algae which as quickly as possible can contribute to actively assimilate the N and P from our fish holding units.

We do not need similar setup for the mussel as they are growing and is not showing such seasonal biomass degradation pattern.

Illustration of seedling station.

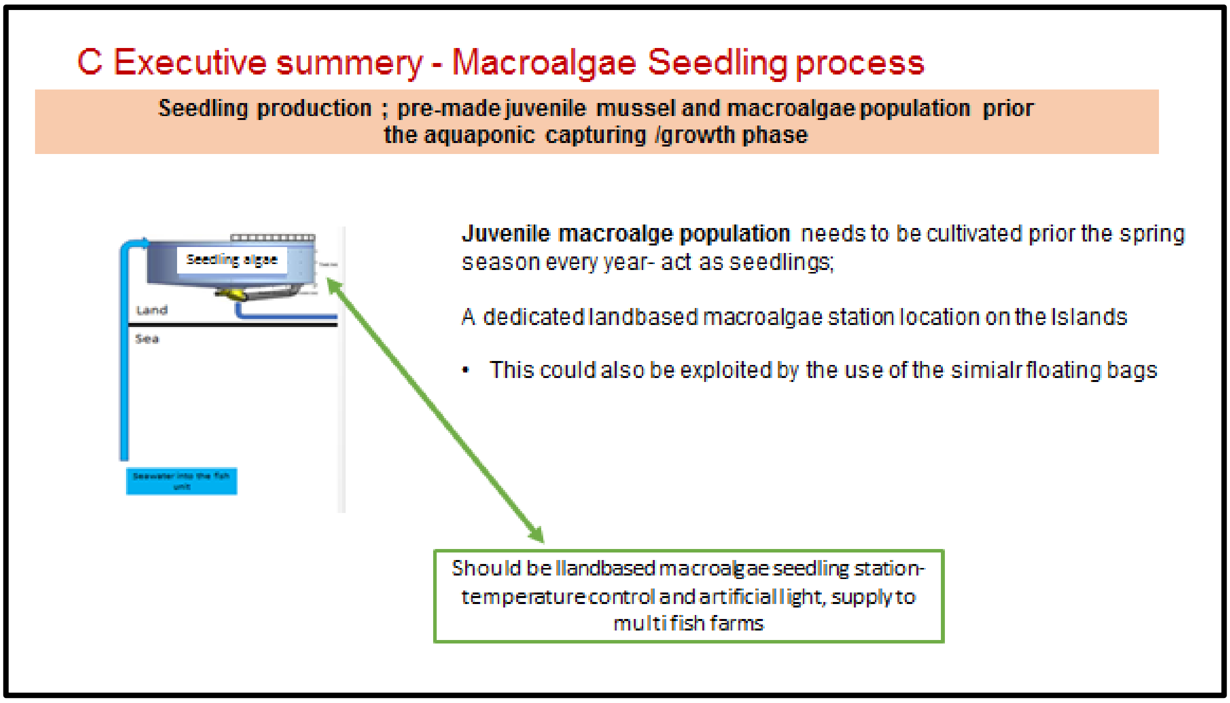
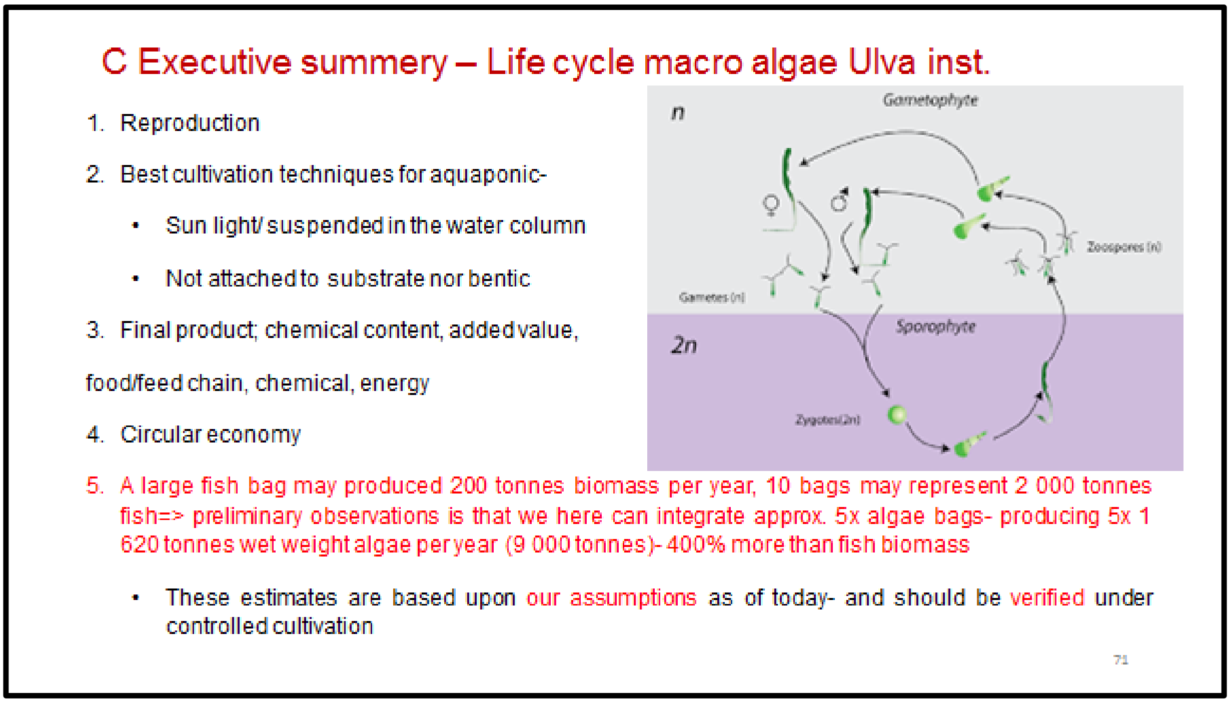


Figure 51. Culturing station macroalgae.

Illustration of lifecycle of the selected *Ulva intestinalis*.



Figures 52. Life cycle of *Ulva intestinalis*

Macroalgae integration to land-based fish tanks and by semi-enclosed floating bag

In a situation where the fish farm is located as a tank construction on land or as semi-enclosed floating large bags/ unit and where they also have a physical/ mechanical filter attached to the outflux water, this results that the amount of organic waste and nutrient flux will be filtered off and the net flux to sea is largely reduced. These “off-filtering compounds” will be dewatered and may act as an energy source as bio-gas and or as a nutrient supplement to the agriculture sector.

These two fish farm alternatives may also be arranged where none mechanical filtering is attached- then the amount of fish waste is increased. This report do only focus upon a situation where the outflux water is passing mechanical filtration. The report is not focusing upon other water treatment setup as RAS I and RAS II with denitrification and chemical settling techniques- as these elements is very technical based and is not part of the scope of this aquaponic structured Report. However, such high tech and more costly waste treatment may certainly represent positive contribution to the fluxes and will also show large flux reductions.

- The interesting thing is that biofilter as a nutrient reduction medium is best setup where one recirculates the water - whereas some new techniques does not require such a setup - making alternatives for none - RAS platforms.

Within this waste technology sector there is a waste new setup and we are familiar with brand new techniques that may eliminate total N fluxes without investing in biofilter nor chemical settling setup- and such new treatment may also be integrated to fish tanks and floating individual bags for fish production. We strongly encourage West Estonia authorities to pay attention to these developments and is is very worthwhile spending time and effort in this direction.

<u>With an integration of macroalgae and mussel capturing of organic waste particles we have a total fluxes to the West Estonia zone as follows:</u>

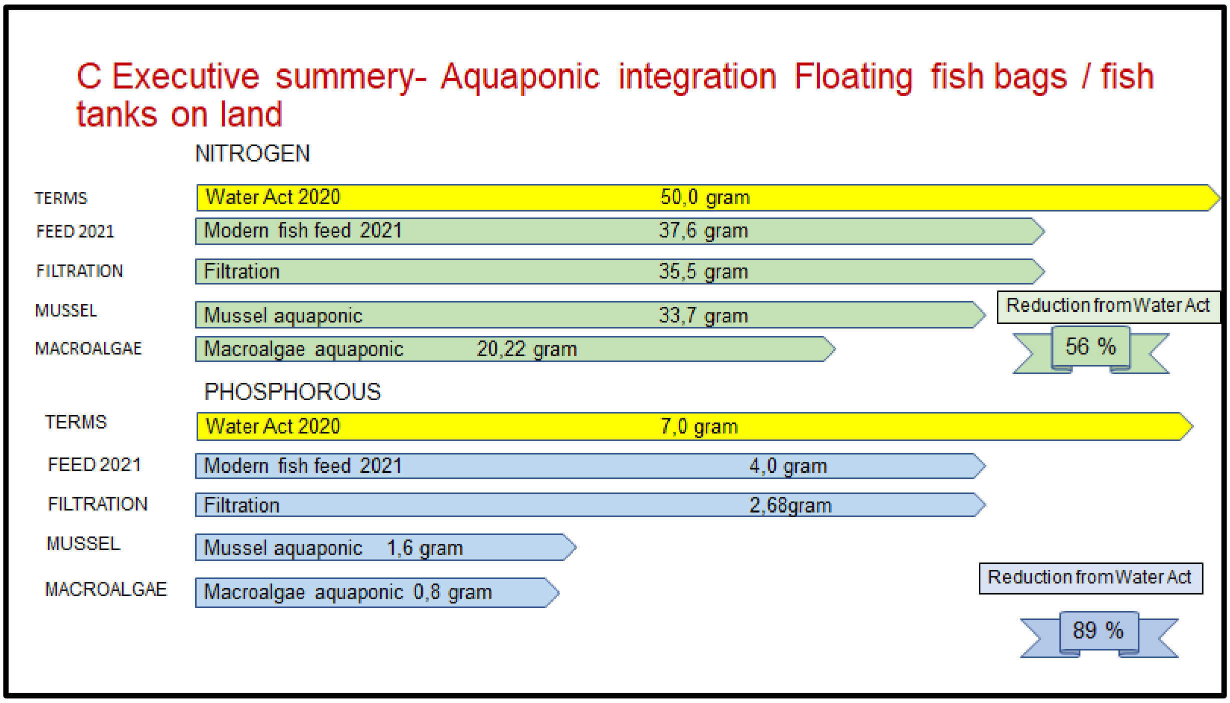


Figure 53. Net fluxes after complete aquaponic integration.

Figure 53 shows a potential where the total Nitrogen flux is reduced by 56% and total Phosphorous is reduced by 89%. This requires both

- mechanical water filtration from the fish thanks/bags
- mussel aquaponic, followed by
- macroalgae aquaponic

As most of the nitrogen is dissolved as inorganic nutrient to the free water column- the mussel filtering activity has minor flux reduction impact (see level from 35.6 => 33.7 grams/kg fish produced).

The macroalgae show a potential where the flux reduction of Nitrogen per kg fish produced is reduced from 33.7 gram to 20.22 gram after the mussel section. Similar for Phosphorous the flux is reduced from approx. 1.6 gram to 0.8 gram.

The algae biomass produced 1 620 tonnes wet weight takes place a year where the fish biomass produced by the adjacent 2x fish bags represent 400 tonnes live fish weight.

Conclusion: If these assumptions do represent realistic directions +/- 20%, this illustrates the importance for West Estonia Government where alternative thresholds of fluxes and alternative fish farming platforms should be considered.

Phosphorous is showing an opposite direction where large quantity is captured both by the mechanical water filtration and by the mussel filtration. The selected *Ulva intestinalis* shows also a very high assimilation capability of dissolved phosphorous.

It is worth mentioning here that all organic suspended particles entering these two aquaponic setups both land-based and from floating fish farming concepts is considered to be fully captured by the filtering mussel population.

This leads to total flux reduction of the particle where the bound P and N content of this waste sludge is eliminated. However, the dissolved N and P in the water column itself is not captured either by the mechanical water filtration nor by the mussel filtration.

These 2 conclusions are important to pay attention to for West Estonia the way forward.

The mechanical water filtration is considered to capture 55% of the gross organic waste from the fish units illustrating that the let over 55% is considered to be of the finer dust fraction of this waste. This smaller particle fraction is here considered to be best suited for mussel capturing. Various manufacturers of modern mechanical water filtration argue that the capturing effect is even larger, up to 70%.

Precautions: if this assumption is incorrect, then adjustments must be included. However, the modelling of filtration potential of mussels under West Estonian conditions shows that the filtering capacity of mussels is enormous and they are able to capture significantly higher concentrations of suspended solids as used in the current study.

14 Open net fish farming aquaponic restrictions

Open net framing with macroalgae production

We have considered that the best macroalgae species, which has a good assimilation update of Nitrogen and Phosphorous, *Ulva intestinalis*, is not suited for any cultivation technics in the free water masses. The algae are fragile and will not withstand waves and currents and will there for be fragmented and algae particles will be lost to the sea and will not represent any out-flux impact. We have therefor considered that Open net farming with aquaponic algae in West Estonia is somewhat challenging, special for the *Ulva intestinalis*.

In other regions, special outside Baltic Sea there is much larger possibility to culture larger brown algae by vertical rope cultivation techniques close to open net farms where its harvest will represent some flux reductions. However, these fluxes are not very high as they are dissolved into a waste volume of free water masses, second the algae cultivation distance from the fish nets also represent a natural large diluting effect.

The selected *Ulva intestinalis*, green grass is illustrated.

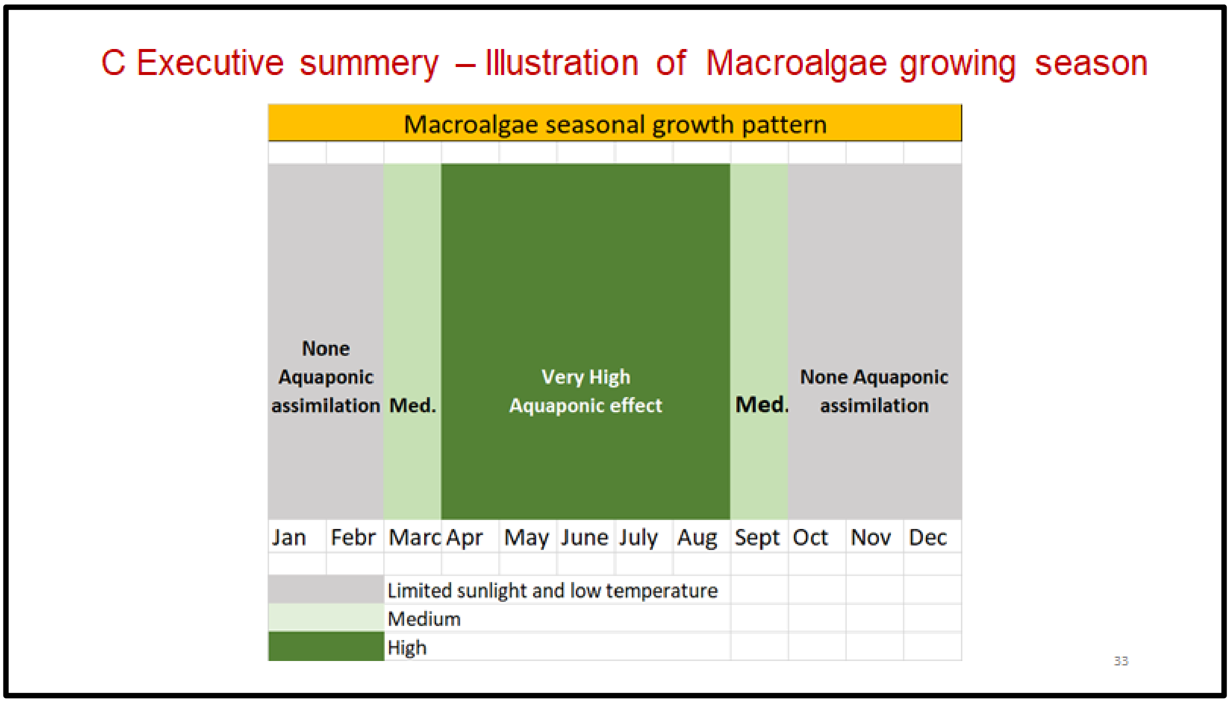


Figure 54. Growth potential of *Ulva intestinalis*.

A seasonal growth pattern illustrated in Figure 54, where the present of good spring/summer light with natural high dissolved nutrients in the free water column motivates for a very good growth pattern. Natural growth can be as high as 3-5% per day which is very high.

In the winter and late autumn the situation is changed; sun light is reduced or absent and the natural concentration s of nutrient is reduced. This leads to similar growth potentials and restrictions when we are integration the algae to our fish farms- tanks on land and floating bags.

We will only have positive algae growth in the same periods, however our water flux with highly dense nutrients load passing from the mechanical filtrations at the fish units is directed in an enclosed water loop to the algae bags without loosing any nutrients.

This has enormous advantages far beyond normal observed among aquaponic setup. Integration with mussel and macroalgae for Open net in the free water column will never ever show such performance. Because out macroalgae is inside its algae bags suspended in the water column by the incoming very nutrient rich water, combined with ideas of aeration inside the bag to create a steady circulation of nutrient, algae and water masses. These ideas should be verified- but from smaller scale trials we consider this to be a good solution.

Macroalgae shows a steady growth pattern for 8x of 12x months each year. Nutrients are lost in the no-productive 4 winter months resulting in outfluxes of N and P to the sea. However, the photosynthesis capability is very large and our model assume that we will have a growth potential of up to 10% per day in the wet weight consideration.

This 10% per day results in a doubling of the algae biomass every 7th days and one have to harvest very frequently, minimum 2x/week. The other result is that our loads of N and P is so high that we consider to have a vast amount of algae suspended in each algae bag.

The algae bags are considered to be a light version of the fish bags, with volume of 6 200 m^3, 10 m deep and a diameter of 28 meter. Such an algae unit will be receiving water pushed by the overpressure from the fish holding bags.

Our baseline fish bags are capable of producing approx. 223 tonnes live weight per 12 months period. This biomass gain is reflecting in a quantity of fish feed which results in our waste matrix flow. For every 2x sets of these fish bags one could consider having 1x algae bag installed at the same location. This large bag is capable of producing and harvesting approx. 1 623 tonnes wet weight algae per year, if our assumptions are correct. There will be +/_ 20 % from this. One critical issue is the assimilation rate according to the flow rate of the nutrient rich water through the algae bag.

If the residence time is too short then we will not have these assimilation ratios shown in this report. The DW dry weigh of the *Ulva instestinalis* is approx. 10%. This large algae growth represents a flux of nutrient out of the West Estonia zone.

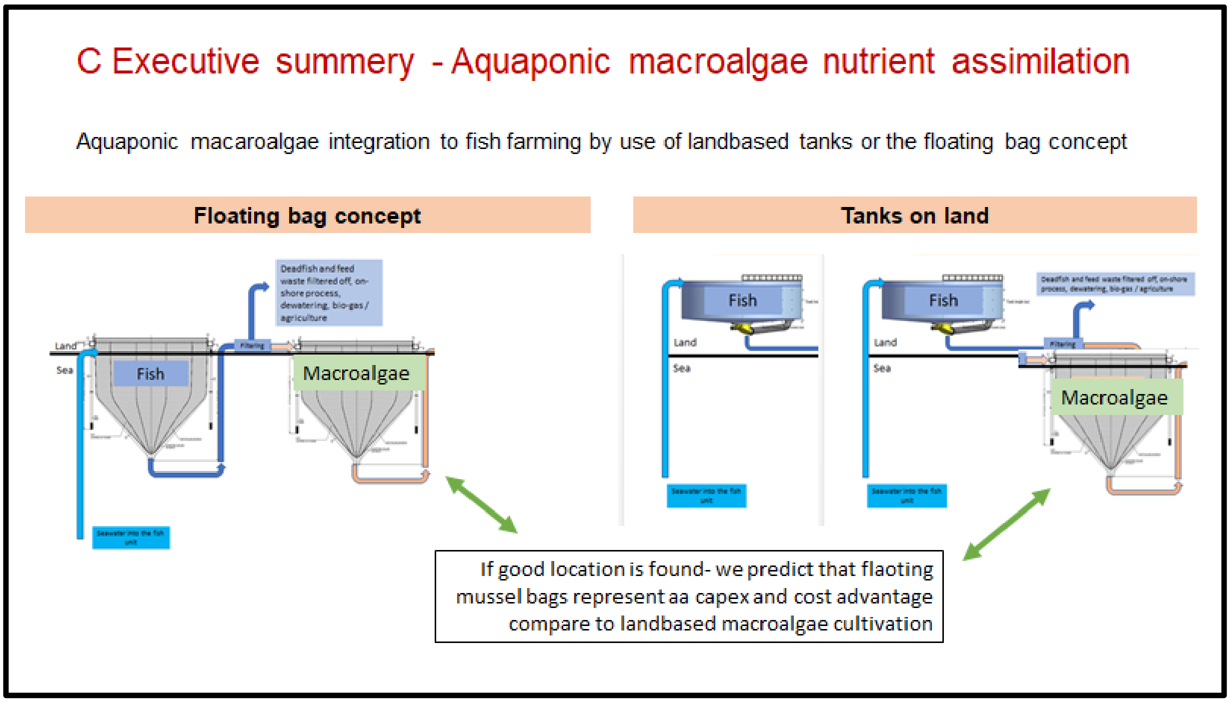


Figure 55. Floating macroalgae aquaponic setup.

An important element for actually be able to integrate an algae aquaponic setup with fish units is that prior every early spring one needs a “battery” of initial biomass of algae held in a cultivation station on land – seedling station. These initial biomass must act as seedling and be ready to be implanted in new start-up algae bags in March month every year. Such a seedling activity could be arranged.

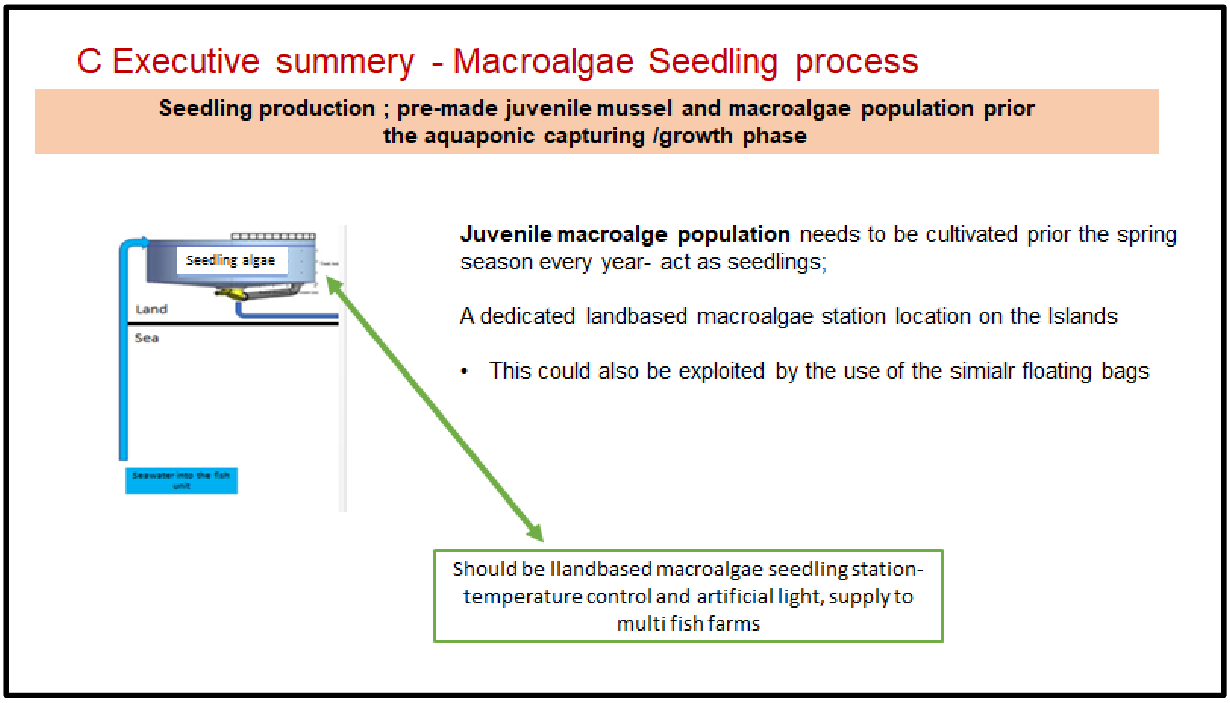


Figure 57. Algae cultivation station.

The seedling station for algae need temperature control and artificial light and seawater pumped onshore. Biological station or the university could initial such a setup and private stakeholders could carry out this production to aquaponic fish farmers or as a JV with authorities.

Of other important flux results by macroalgae production are

- the avoidance of predation of the growing cohort, one should be able to monitor growth, quality and harvest to ensure optimum out-fluxes of nutrients.
- That the photosynthesis also results in a direct oxygen production, which takes place inside the algae bags - how this can be utilized by the fish farm is currently not looked into. There is similar large quantity of carbon dioxide reduction in the water column.

D Observations – Cultivation elements West Estonia - macroalgae

Cultivation elements Macroalgae

Why Ulva intestinalis- green grass?

- Natural present in West Estonia region
- Growth season, assimilation of nutrient, sunlight photosynthesis
- summer intensive growth
- winter hibernation and small growth
- winter fragmentation

Oxygen production and carbon dioxide reduction

Fragile algae

- bad weather and wave forces damage the algae
- **Offshore cultivation is difficult**

Algae bags => advantages in form of;

- is protected, conserve all nutrient flux and carbon dioxide to the algae
- circulation of nutrient rich water and algae inside the algae bag

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D Observations – Cultivation elements West Estonia - macroalgae

Cultivation elements Macroalgae

Technical challenges;

- sedimentation of macroalgae must be avoided
- algae suspended in the water column must also avoid shadow effect / limited sunlight
- What is the actual growth rate?
- How to harvest?
- How to operate the units?
- How to avoid epizoon and predation?
- Intensive growth season- huge volume

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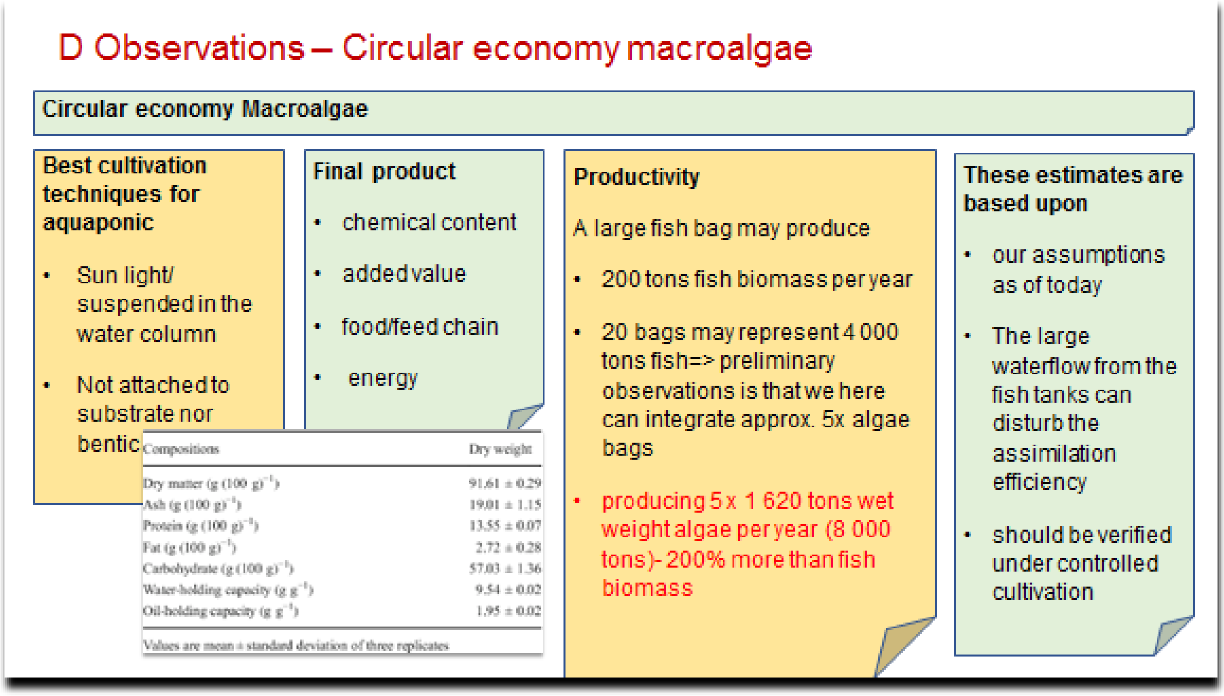


Figure 58. Elements for macroalgae offshore cultivation.

Open net farm integration with shellfish

A third fish farm alternative is the use of traditional open net cages, the well-known salmonid fish production strategy. Open nets have no collection of the waste which is freely drifting away from the farm where the sea current/ water movements do spread and dilute the waste over a large area including both solid particles and dissolved nutrients as nitrogen and phosphorus.

Illustrations of fish farm platform with mussel aquaponic integration.

This section illustrates our observation related to mussel cultivation.

The lifecycle of the blue mussel *Mytilus edulis* is as follows.

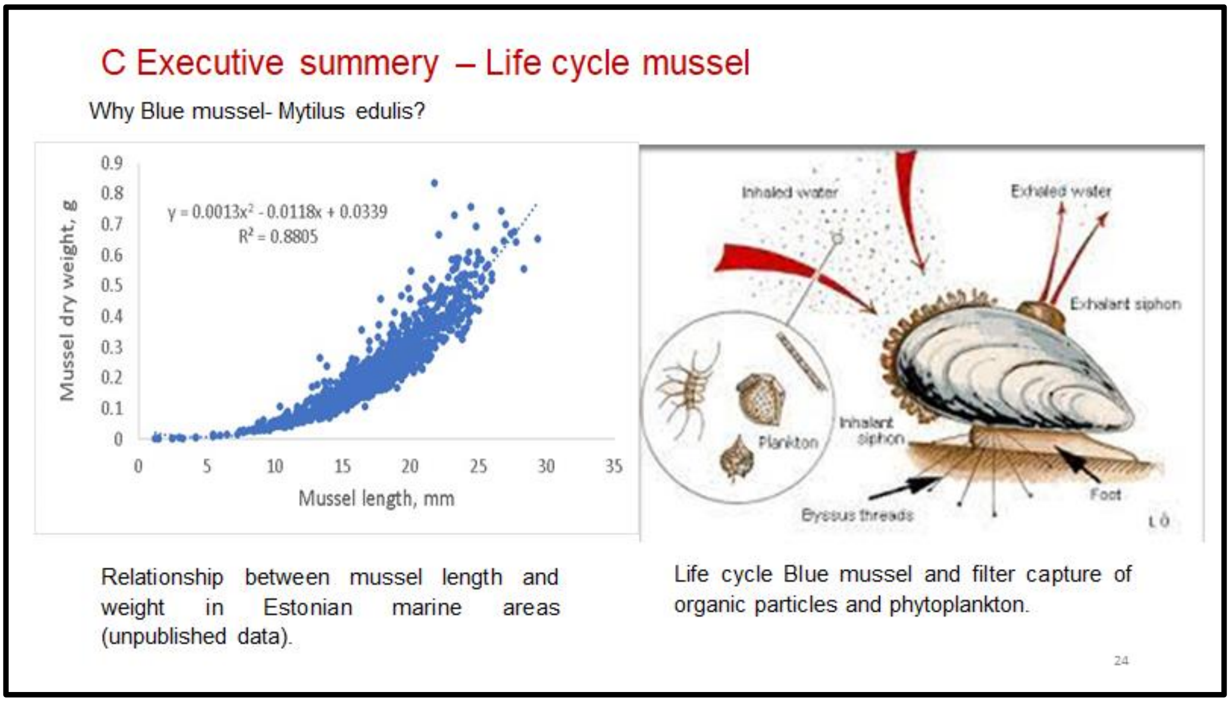


Figure 59. The lifecycle of the blue mussel *Mytilus edulis* and allometric relationship between length and weight in West Estonia.

An aquaponic integration of the mussel

The seasonal variability in the filtration potential of mussels.

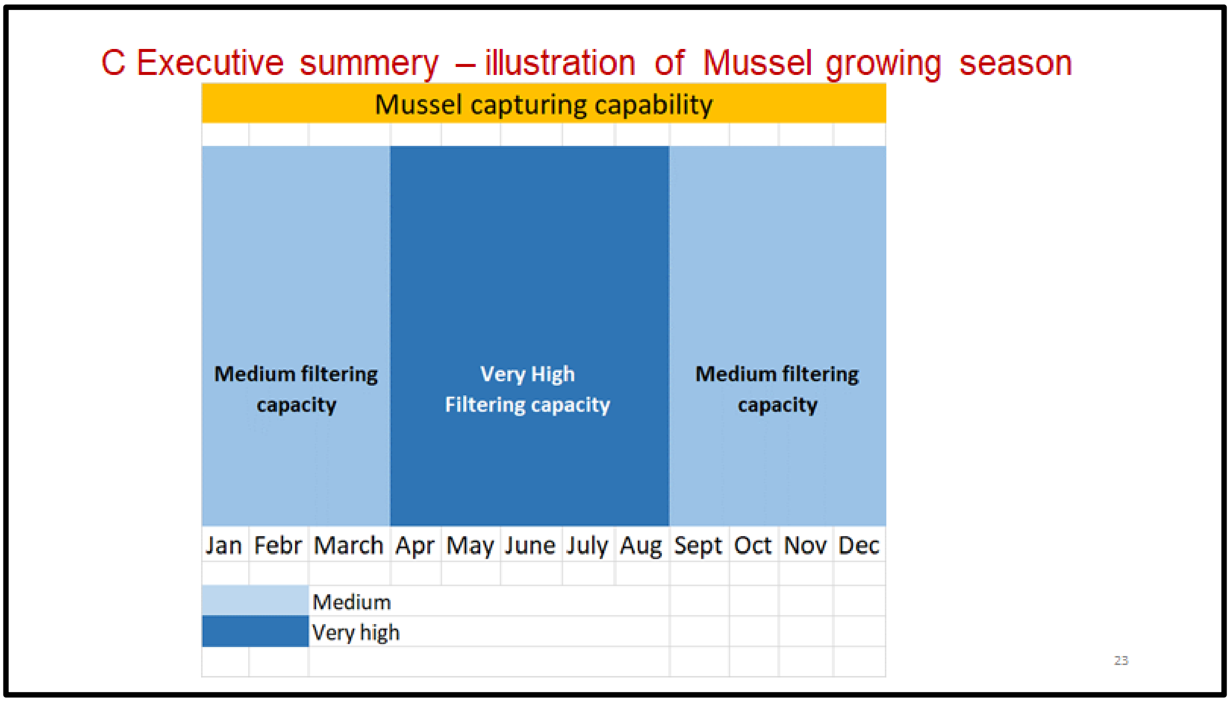


Figure 60. Seasonality in the filtration potential of mussels.

Comments:

- The very interesting aspect of an integration of the mussel to fish holding units is that for land-based fish farms there is a steady 24/7 flux of fine organic suspended particles year round.
- The mussel will respond to this by realizing that even in wintertime and lower temperatures the mussel may benefit by a net gain.
- Severe low temperatures may create ice particles in the water column and under such conditions the filtering potential of mussels is reduced.
- So by pumping deeper sea water into our enclosed fish units the mussel will not experience any severe low temperature effects and is showing a "steady" growth pattern year round.

Our model for mussel growth shows that for every 2x commercial large fish bags one could hold 1x mussel bag that produces approx. 24 tonnes live weight with shell. However, one need a seedling production of smaller juvenile mussel after harvesting of every mussel unit to allow for a good capturing effect of all finer organic particles. This mussel seedling should take place in the sea where normally used hanging cultivation techniques by nets/ trawler nets will allow the juvenile stage veliger to attach itself to the surface of the nylon. After approx. 9 months of natural growth these smaller mussels reach a size where they are capable of capturing all the organic waste from one fish bag.

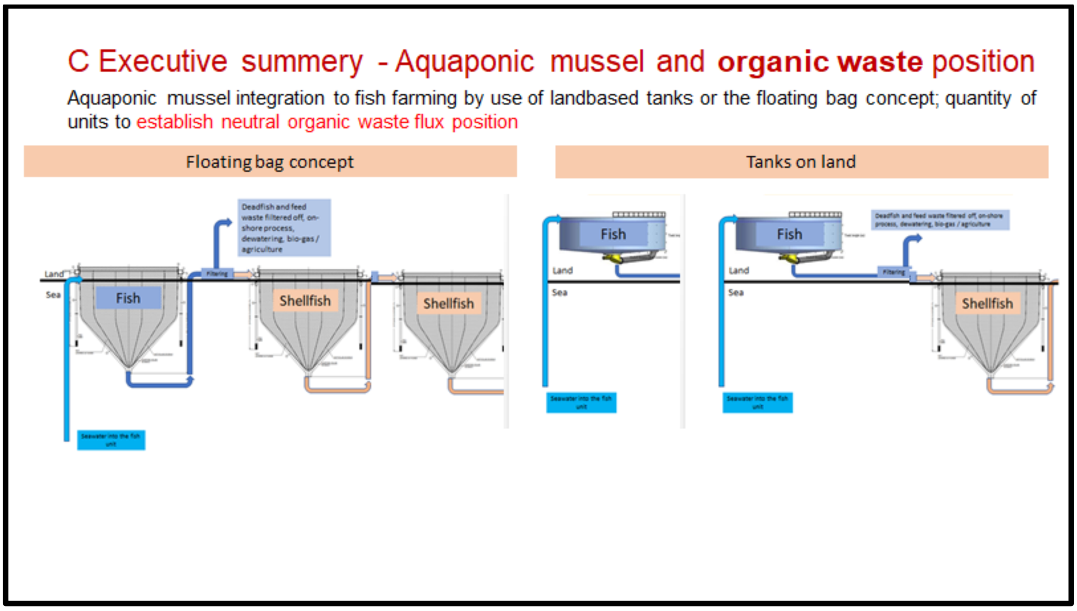


Figure 61. Integration of mussel aquaponic unit to on land and offshore fish farms.

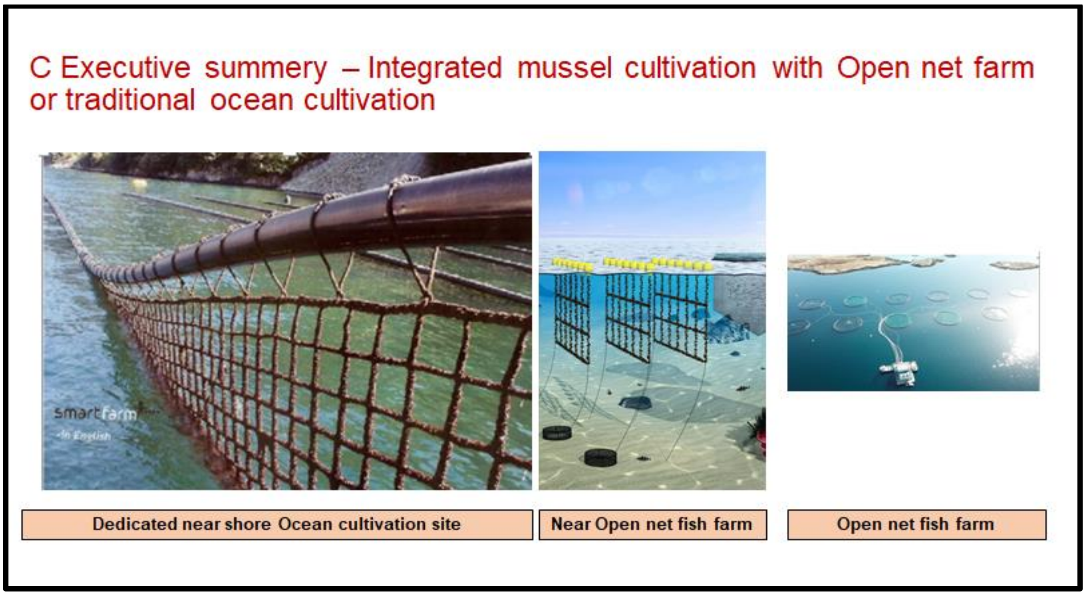


Figure 62. Seedling and offshore cultivation of mussels.

<u>Mussel assumptions</u>

In our model we have considered the following realistic assumptions:

- Inside the mussel bag there is no predation of the growing mussel.
- We also expect no diseases causing severe mortality.
- Seedling is provided at dedicated volume and time of year.
- Mussels are growing attached to trawler nets or similar substrate, handing vertical inside the bags.
- We need a new structural frame and lifting devices for inspection, cleaning and harvesting the mussels.
- Nets have to be installed close to each other.
- All these elements will have large impact on the setup, its cost and its growth potential.

An alternative very interesting aspect by mussel aquaponic setup is that the biomass yield of the mussel is of interest, but also its filtering capability as such. The mussel main function is to capture the suspended organic particles, not necessary to results in biomass yield. So for its main function i.e. capturing particles one could leave the cultured mussel in the bag for a very long periods – years.

- By doing so one will ensure that fish tanks have a aquaponic capturing device functional all the time.
- In this strategy the net gain in mussel biomass is not that interesting.
- However, fish farmers in future may optimize this procedure by applying mussel seedling at a higher frequency.

Other mussel cultivation results

- The growth of the mussel also represents a binding of carbon to the shell $CaCO_3$ - carbonate.
- This carbonate represents an out-flux of carbon.
- If this is assumed to mainly come from the carbon dioxide, each ton live weight mussel can compensate 123 kg CO_2 outflux.
- Per mussel bag integrated to 2x fish bags one could harvest 24 tons mussel per year.

Below is an illustration of the normal waste routes in the marine ecosystem

- The largest waste fraction is the result by the digestion of the fish feed, dominated by fat, protein and carbohydrate. The faeces is large fragile particles suspended in the water column either filtered off at the tank and or floating bag fish farm or is passive entering the open sea through the current of the open net farm.

- This waste is broken down to smaller particles, some are regimented on the seabed, other fractions are degraded and do enter the marine ecosystem through normal routes. The smallest micro particle fraction of the organic waste is not able to be collected by mechanical filtration, the same is also for soluble nutrient (nitrogen and phosphorus). These suspended particles and the dissolved soluble nutrients will be assimilated by the algae and by the shellfish to variable degree depending upon if they are tight or loosely bounded to the fish farm.

- Beside the suspended nutrients a third important waste product is the carbon dioxide which is the by-product from the oxygen combustion by the fish population. It acts as a direct energy source and acts also as a building structural "backbone" for the produced macroalgae, which also results in an oxygen production by the photosynthesis process.

- The shellfish section of the aquaponic unit act as a filter of the smallest suspended particles from the fish waste into marine protein/mussel muscle.

15 Potential circular economy impacts

The overall potential for circular economy.

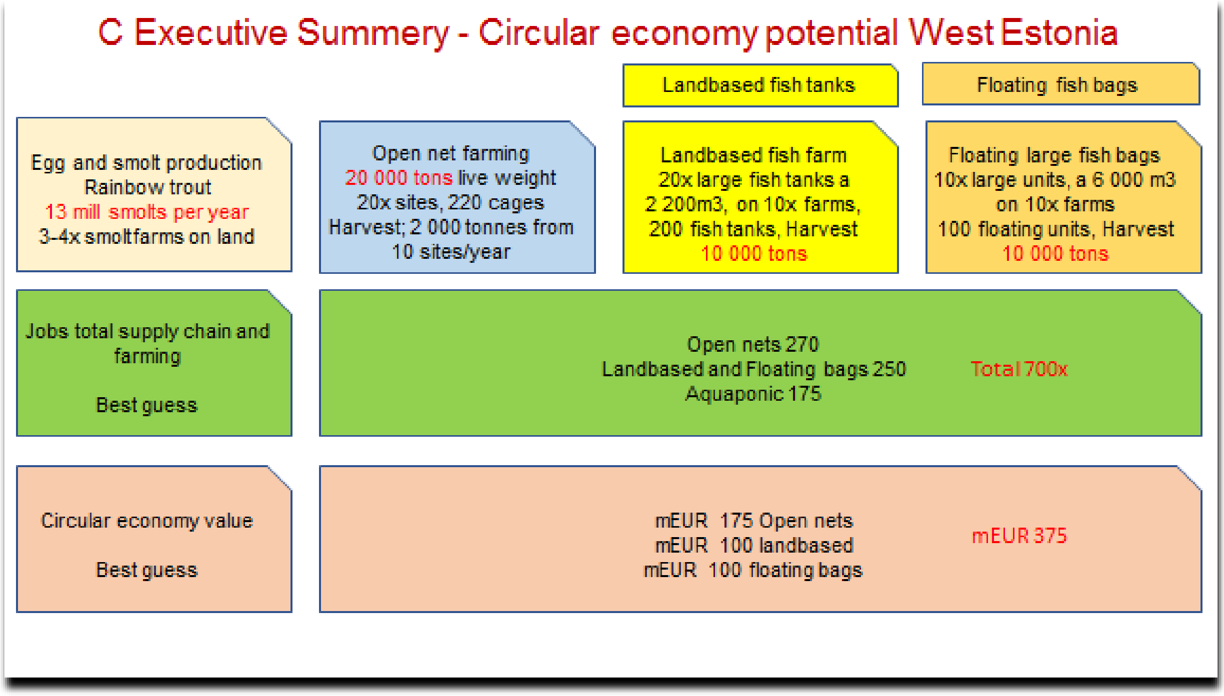


Figure 63. Shows the potential circular economy for the exploitation of the West Estonia coastal resources.

<u>Comments</u>

The comments are addressed in the Executive summery. It is important to establish a good foundation for 2-4x semi-large modern smolt plants. These farms are vital for the exploiting of on growing large rainbow trout for the region.

16 Risk elements

Main risk elements are illustrated as:

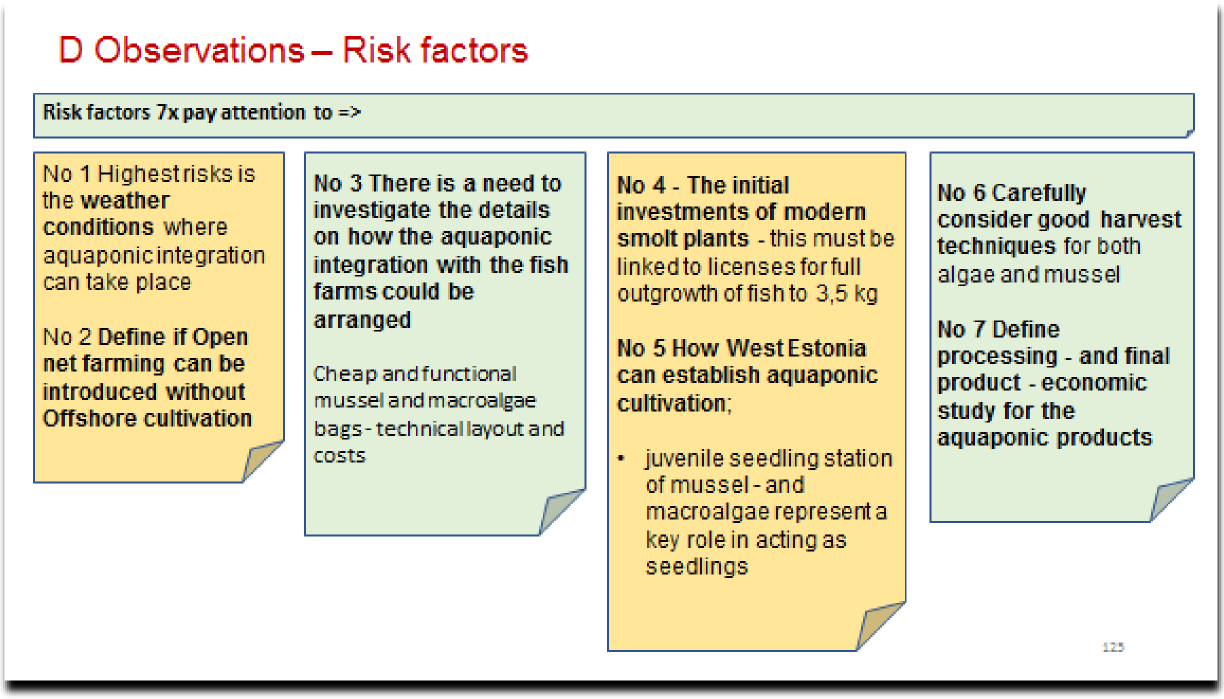


Figure 64. Main risk elements.

Comments

Relevant comments are listed in chapter 3 Executive summary. We stress that good location for all 3x platforms for production of large rainbow trout must be evaluated with special focus on weather conditions. It is also important that traditional Open net farming licenses is granted - even these represent a higher waste fluxes compared to the enclosed platforms. They could be given reasonable quotas for flux per year per site. This will allow for a lower cost entry for private stakeholders. One strategy could be to do so, and these and or additional permits could be granted where more advanced waste treatment is honoured with a higher biomass and waste fluxes.

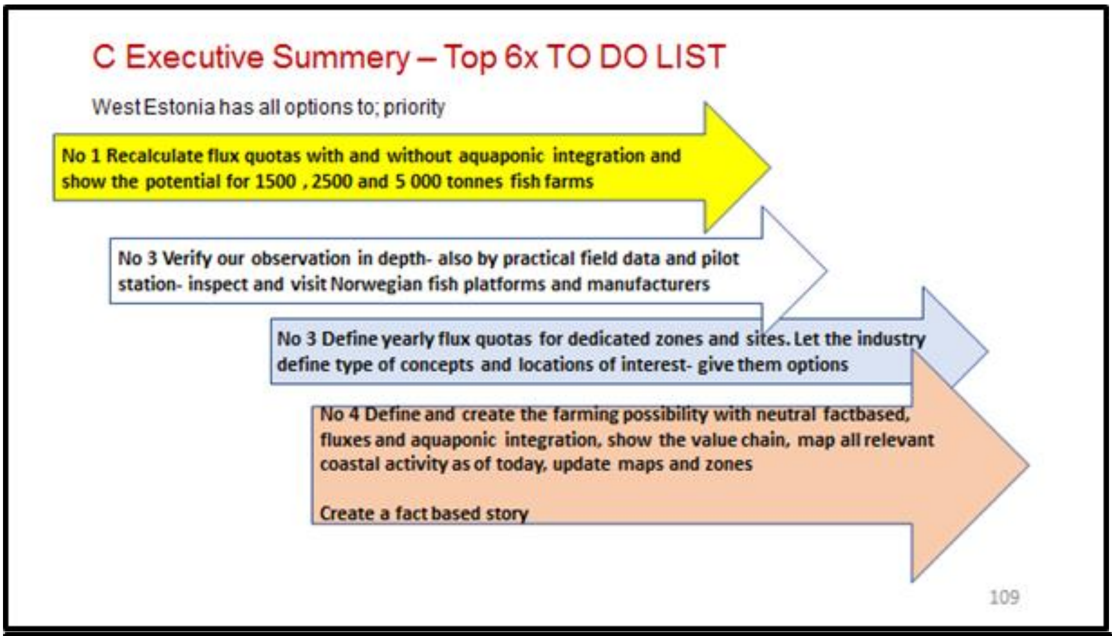
We assume that caused by a future potential limitation of fish farming activity in general in Baltic Sea there may be an advantage for first movers. However, as the eutrophication is as such - a careful licenses regime should be founded where site specific licenses both in a short and a longer perspective are “equally” ranked according to waste impact on defined single locations.

A success for waste reduction is how the aquaponic integration and cultivation techniques are established. We encourage public R&D and resources to initiate trials where our listed pilot R&D stations is vital. We assume that any resources dedicated for this may represent:

- Quick preliminary observations under active production of fish and aquaponic is small/ semi-large scale for a 3 year period.
- Followed by licenses introduction plan.
- Allow the industry to select the fish platform they want, and adjust waste fluxes accordingly.
- The public sector should not demand that certain platforms are better than others as long as key focus is quantity of fluxes to the environment.

17 Action plan for West Estonia Government

The main TO DO elements may be part of a TO DO list for West Estonia Municipalities WEM.



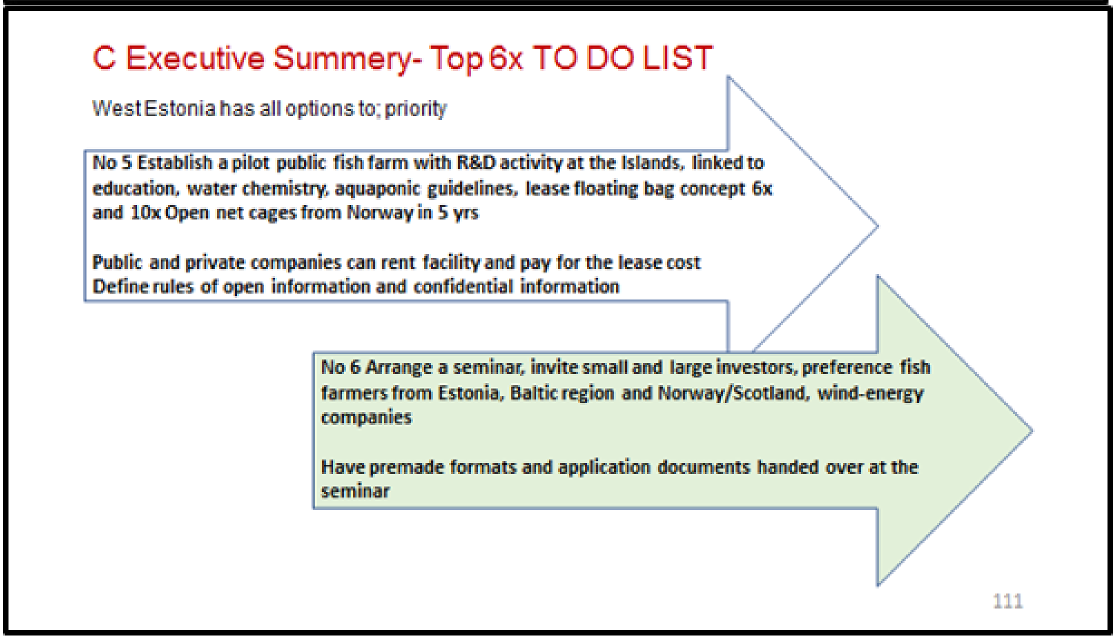


Figure 65. TO DO elements.

<u>Comments;</u>

These elements are here considered to be important. For text and illustrations of TO DO elements are listed in Appendices.

Appendices

A Fish farming production planning elements/ background

The sea temperature is low in winter approx. 3 degrees and reach a peak of approx. 16 Celsius in August/September. The growth curve of various fish groups entering the Open net cages during the spring/ summer period.

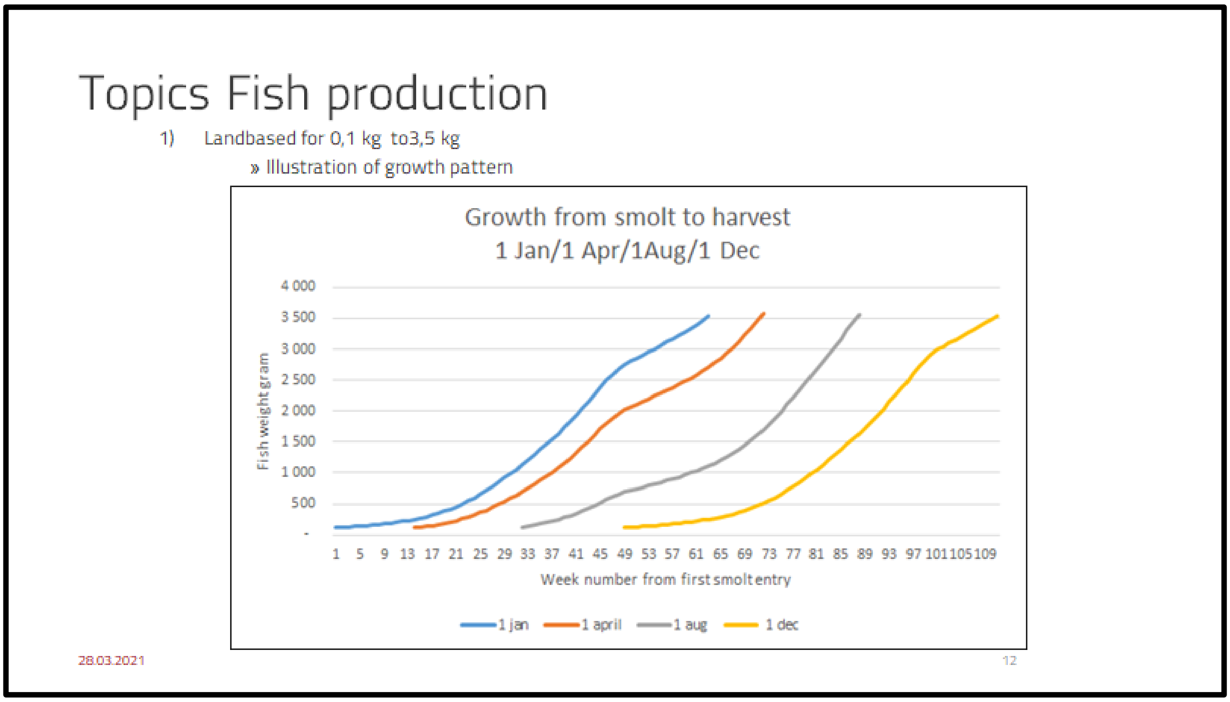


Figure 63 Growth pattern for land based and floating bag platform- different fish groups released at different time.

The growing period lasts from approx. 53 weeks up to approx. 57 weeks depended upon the temperature profile. Shorted generation time is for fish groups who experience the best temperature profile for its whole generation.

<u>Production planning</u>

It is important to have a steady state of biomass at the fish farm year round so that the production can reach biomass volume where the economy of scale is utilizing the investment and thereby allows the fish farmer to reach a good economy. Without such a production planning the fish farm will have difficult cashflow positions and may also have a limited season window for its harvest and sales.

This is normally arranged where trout smolts are entered the fish farm at dedicated times of the year. In our production planning we have chosen all smolt of 100 gram and have estimated the number of smolt for the open net cages, the enclosed floating bags and the modern fish tank configuration onshore, so that they all can produce and harvest biomasses of economical dimension.

The floating bag concept and the fish tanks on land is having identical growth, survival and biomass year round. The Open net cages in our internal demo for predicting fish feed volume week by week and its wastes to the sea is having a less frequent smolt entry and a different biomass development.

The figure below shows how each smolt group develop tis individual biomass over time until the harvested live weight of 3,5 kg is reached. After harvest the fish tanks or the floating bags can be restocked with a new fish groups that is released at another time of the year and therefor has its separate growth pattern for its lifecycle. We have done this for approx. 170x different smolt entries to predict the steady state in the 3 where the biomass and fish feed volume is showing smooth and stable performances. From this status we have estimated the nutrient fluxes as bound to particle and being dissolved in the free water column.

From these fluxes we have then integrated the aquaponic elements to tanks on land and to the floating bag units.

Biomass kg, end of week per fishgroup

Year	Month	Week	Temperature	01.01.2021 Biomass kg, end of week	15.01.2021 Biomass kg, end of week	01.02.2021 Biomass kg, end of week	15.02.2021 Biomass kg, end of week	01.03.2021 Biomass kg, end of week	15.03.2021 Biomass kg, end of week	01.04.2021 Biomass kg, end of week	15.04.2021 Biomass kg, end of week	01.05.2021 Biomass kg, end of week	15.05.2021 Biomass kg, end of week	01.06.2021 Biomass kg, end of week	15.06.2021 Biomass kg, end of week	01.07.2021 Biomass kg, end of week	15.07.2021 Biomass kg, end of week	01.08.2021 Biomass kg, end of week	15.08.2021 Biomass kg, end of week	01.09.2021 Biomass kg, end of week	15.09.2021 Biomass kg, end of week	01.10.2021 Biomass kg, end of week	15.10.2021 Biomass kg, end of week	01.11.2021 Biomass kg, end of week	15.11.2021 Biomass kg, end of week	01.12.2021 Biomass kg, end of week	15.12.2021 Biomass kg, end of week
2021	1	1	4,0	6 797																							
2021	1	2	4,0	7 217																							
2021	1	3	4,0	7 659	6 797																						
2021	1	4	4,0	8 124	7 217																						
2021	1	5	4,0	8 613	7 659	6 797																					
2021	2	6	4,0	9 127	8 124	7 217																					
2021	2	7	4,0	9 666	8 613	7 691	6 826																				
2021	2	8	4,3	10 272	9 164	8 224	7 306																				
2021	2	9	4,5	10 950	9 782	8 811	7 837	6 872																			
2021	3	10	4,8	11 692	10 460	9 468	8 432	7 403																			
2021	3	11	5,0	12 517	11 216	10 214	9 109	8 009	6 933																		
2021	3	12	5,4	13 448	12 071	11 057	9 877	8 697	7 540																		
2021	3	13	5,8	14 493	13 032	12 005	10 742	9 476	8 230	6 998																	
2021	4	14	6,2	15 662	14 111	13 070	11 717	10 356	9 012	7 678																	
2021	4	15	6,6	16 965	15 316	14 261	12 810	11 347	9 896	8 449	7 058																
2021	4	16	7,0	18 413	16 659	15 603	14 045	12 470	10 902	9 332	7 815																
2021	4	17	7,5	20 032	18 165	17 108	15 436	13 738	12 043	10 338	8 681	7 128															
2021	4	18	8,0	21 836	19 847	18 790	16 995	15 166	13 332	11 479	9 671	7 965															
2021	5	19	8,5	23 838	21 719	20 664	18 735	16 767	14 783	12 771	10 798	8 924	7 193														
2021	5	20	9,0	26 050	23 793	22 808	20 736	18 612	16 465	14 276	12 116	10 055	8 137														
2021	5	21	10,0	28 564	26 156	25 229	23 003	20 713	18 387	16 006	13 643	11 374	9 246	7 348													
2021	5	22	11,0	31 379	28 812	27 922	25 534	23 066	20 550	17 963	15 383	12 890	10 534	8 445													
2021	6	23	12,0	34 482	31 751	30 857	28 301	25 652	22 939	20 138	17 329	14 598	11 997	9 680	7 382												
2021	6	24	13,0	37 836	34 937	33 993	31 267	28 434	25 522	22 502	19 457	16 479	13 622	11 059	8 492												
2021	6	25	13,4	41 394	38 326	37 317	34 422	31 403	28 290	25 048	21 764	18 531	15 411	12 583	9 733	7 383											
2021	6	26	13,8	45 137	41 900	40 812	37 749	34 547	31 232	27 767	24 240	20 750	17 358	14 248	11 104	8 484											
2021	7	27	14,2	49 047	45 645	44 456	41 229	37 843	34 330	30 643	26 874	23 123	19 457	16 049	12 600	9 700	7 366										
2021	7	28	14,6	53 098	49 536	48 223	44 834	41 270	37 561	33 655	29 647	25 639	21 696	18 008	14 245	11 051	8 451										
2021	7	29	15,0	57 260	53 540	52 169	48 619	44 878	40 971	36 847	32 599	28 330	24 106	20 131	16 045	12 542	9 663	7 366									
2021	7	30	15,0	61 596	57 721	56 292	52 583	48 666	44 563	40 219	35 729	31 199	26 690	22 422	18 004	14 182	11 009	8 451									
2021	7	31	15,0	66 108	62 080	60 594	56 725	52 633	48 335	43 772	39 039	34 246	29 450	24 886	20 127	15 977	12 496	9 653	7 359								
2021	8	32	15,0	70 793	66 612	65 070	61 044	56 778	52 285	47 506	42 529	37 472	32 389	27 500	22 396	17 911	14 116	10 966	8 418								
2021	8	33	15,0	75 649	71 318	69 667	65 488	61 052	56 369	51 376	46 161	40 845	35 475	30 237	24 792	19 973	15 860	12 396	9 585	7 334							
2021	8	34	15,3	80 614	76 137	74 336	70 009	65 408	60 542	55 344	49 897	44 328	38 679	33 102	27 317	22 164	17 728	13 926	10 846	8 356							
2021	8	35	15,5	85 634	81 018	79 086	74 617	69 856	64 813	59 414	53 741	47 926	42 002	36 057	29 941	24 457	19 703	15 663	12 288	9 537	7 350						
2021	9	36	15,8	90 724	85 974	83 855	79 249	74 337	69 125	63 532	57 644	51 591	45 401	39 311	32 846	27 012	21 916	17 603	13 916	10 878	8 441						
2021	9	37	16,0	95 814	90 938	89 018	84 270	79 198	73 807	68 014	61 898	55 595	49 128	42 849	36 020	29 818	24 362	19 742	15 725	12 383	9 675	7 383					
2021	9	38	15,4	101 316	96 306	94 533	89 637	84 400	78 825	72 823	66 471	59 912	53 155	46 648	39 442	32 861	27 032	22 075	17 710	14 048	11 053	8 493					
2021	9	39	14,8	107 181	102 033	100 354	95 308	89 902	84 136	77 924	71 331	64 506	57 454	50 679	43 090	36 123	29 912	24 585	19 864	15 870	12 573	9 728	7 376				
2021	10	40	14,2	113 360	108 071	106 435	101 234	95 657	89 700	83 275	76 437	69 346	61 994	54 914	46 940	39 580	32 983	27 247	22 165	17 829	14 220	11 077	8 453				
2021	10	41	13,6	119 803	114 370	112 723	107 369	101 620	95 473	88 832	81 750	74 392	66 738	59 303	50 946	43 194	36 209	30 036	24 590	19 910	15 983	12 534	9 626	7 290			
2021	10	42	13,0	126 454	120 878	119 152	113 645	107 725	101 388	94 535	87 210	79 586	71 635	63 802	55 068	46 930	39 559	32 910	27 103	22 083	17 836	14 078	10 879	8 244			
2021	10	43	12,3	133 241	127 523	125 650	119 993	113 907	107 384	100 122	92 761	84 876	76 632	68 342	59 241	50 728	42 982	35 845	29 687	24 329	19 767	15 698	12 207	9 191	7 162		
2021	10	44	11,5	140 090	134 233	132 139	126 317	120 071	113 368	106 105	98 314	90 179	81 652	72 886	63 435	54 561	46 454	38 632	32 154	26 489	21 634	17 277	13 510	10 090	7 889		
2021	11	45	10,8	146 897	140 906	138 509	132 568	126 169	119 294	111 840	103 829	95 455	86 657	77 111	67 349	58 154	49 721	41 149	34 398	28 466	23 356	18 745	14 730	10 887	8 539	6 941	
2021	11	46	10,0	153 608	147 490	144 356	138 293	131 759	124 734	117 112	108 908	100 323	91 287	80 838	70 818	61 355	52 648	43 273	36 305	30 159	24 841	20 021	15 801	11 509	9 050	7 368	
2021	11	47	8,5	162 000	153 507	149 420	143 259	136 614	129 463	121 706	113 343	104 585	95 352	83 902	73 684	64 013	55 094	44 834	37 718	31 423	25 961	20 991	16 623	12 157	9 585	7 818	6 797
2021	11	48	7,0	165 031	158 711	153 496	147 259	140 530	133 286	125 426	116 944	108 055	98 672	86 085	75 738	65 930	56 871	46 426	39 162	32 720	27 113	21 993	17 476	12 834	10 146	8 292	7 217
2021	12	49	5,5	169 278	163 000	156 335	150 048	143 263	135 959	128 033	119 473	110 501	101 020	88 293	77 818	67 876	58 677	48 048	40 637	34 048	28 297	23 027	18 360	13 539	10 733	8 790	7 659
2021	12	50	4,0	172 227	165 796	159 193	152 857	146 018	138 652	130 662	122 024	112 969	103 392	90 526	79 925	69 849	60 512	49 700	42 144	35 407	29 511	24 092	19 274	14 272	11 348	9 313	8 124
2021	12	51	4,0	175 196	168 721	162 000	155 687	148 793	141 367	133 312	124 598	115 461	105 788	92 784	82 058	71 849	62 375	51 381	43 681	36 798	30 759	25 188	20 219	15 036	11 990	9 861	8 613
2021	12	52	4,0	178 184	171 666	164 972	158 537	151 589	144 103	135 983	127 191	117 974	108 207	95 067	84 216	73 876	64 266	53 092	45 248	38 221	32 038	26 317	21 196	15 829	12 659	10 435	9 127
2021	12	53	4,0	181 192	174 631	167 891	162 000	154 405	146 859	138 676	129 810	120 510	110 649	97 374	86 400	75 930	66 185	54 833	46 845	39 674	33 349	27 477	22 203	16 652	13 357	11 035	9 666
2022	1	2	4,0	184 219	177 615	170 829	164 296	157 241	149 636	141 389	132 448	123 068	113 114	99 705	88 609	78 010	68 132	56 602	48 473	41 159	34 690	28 670	23 243	17 505	14 084	11 663	10 231
2022	1	3	4,0	187 266	180 619	173 788	167 206	160 000	152 434	144 124	135 108	125 648	115 601	102 060	90 842	80 116	70 106	58 401	50 131	42 675	36 064	29 894	24 313	18 389	14 840	12 319	10 822
2022	1	4	4,0	190 331	183 641	176 766	170 135	162 974	155 251	146 879	137 788	128 249	118 111	104 438	93 100	82 248	72 107	60 228	51 818	44 221	37 468	31 149	25 416	19 371	15 684	13 052	11 485
2022	1	5	4,0	193 416	186 684	179 764	173 085	165 870	158 000	149 654	140 489	130 873	120 642	106 839	95 382	84 406	74 135	62 234	53 673	45 921	39 016	32 535	26 636	20 458	16 621	13 870	12 226
2022	1	6	4,0	196 520	189 745	182 781	176 053	168 786	160 945	152 449	143 211	133 517	123 196	109 471	97 885	86 772	76 359	64 424	55 700	47 784	40 713	34 058	27 980	21 634	17 638	14 760	13 035
2022	2	7	4,0	199 643	192 826	186 085	179 305	171 980	164 075	156 000	146 193	136 415	125 994	112 338	100 611	89 350	78 785	66 754	57 860	49 770	42 527	35 691	29 424	22 926	18 760	15 746	13 934
2022	2	8	4,0	203 061	196 199	189 679	182 842	175 454	167 481	158 845	149 440	139 570	129 041	115 375	103 501	92 086	81 361	69 278	60 202	51 929	44 501	37 472	31 005	24 366	20 015	16 852	14 944
2022	2	9	4,3	206 779	199 867	193 477	186 582	179 128	171 083	162 371	153 000	142 908	132 267	118 653	106 623	95 042	84 148	72 051	62 778	54 306	46 681	39 440	32 757	25 962	21 412	18 088	16 075
2022	2	10	4,5	210 707	203 744	197 572	190 612	183 089	174 967	166 173	156 579	146 509	135 748	122 245	110 045	98 285	87 204	75 079	65 595	56 908	49 071	41 606	34 690	27 725	22 961	19 464	17 337
2022	3	11	4,8	214 941	207 922	202 052	195 023	187 423	179 217	170 334	160 634	150 000	139 559	126 154	113 770	101 817	90 538	78 369	68 660	59 745	51 681	43 976	36 813	29 663	24 671	20 989	18 741
2022	3	12	5,0		212 492	206 918	199 815	192 133	183 837	174 857	165 043	154 739	143 705	130 383	117 802	105 643	94 153	81 926	71 978	62 823	54 519	46 559	39 134	31 787	26 553	22 673	20 296
2022	3	13	5,4		217 457	212 174	204 991	197 222	188 827	179 745	169 807	159 374	150 000	134 936	122 146	109 769	98 054	85 755	75 557	66 149	57 593	49 365	41 663	34 131	28 639	24 547	22 032
2022	3	14	5,8	7 058		217 819	210 551	202 687	194 190	184 998	174 929	164 358	153 011	139 815	126 806	114 197	102 246	89 910	79 447	69 770	60 946	52 435	44 437	36 707	30 941	26 624	23 961
2022	4	15	6,2	7 815			216 495	208 533	199 926	190 617	180 409	169 692	158 175	145 000	131 841	118 988	106 786	94 394	83 652	73 692	64 587	55 778	47 468	39 527	33 471	28 915	26 096
2022	4	16	6,6	8 681	7 128			214 831	206 107	196 674	186 319	175 446	163 747	150 743	137 251	124 141	111 675	99 210	88 176	77 921	68 522	59 399	50 764	42 598	36 239	31 434	28 449
2022	4	17	7,0	9 671	7 965	7 193			212 727	203 163	192 653	181 614	169 724	156 786	143 000	129 657	116 914	104 358	93 021	82 462	72 755	63 308	54 335	46 036	39 353	34 279	31 114
2022	4	18	7,5	10 798	8 924	8 137				210 078	199 403	188 192	176 100	163 206	149 188	135 530	122 501	110 013	98 355	87 469	77 437	67 643	58 307	49 829	42 806	37 446	34 090
2022	4	19	8,0	12 116	10 055	9 246	7 348	7 382		217 404	206 558	195 169	182 867	170 217	155 913	140 000	128 623	116 117	104 124	92 900	82 528	72 375	62 661	53 942	46 569	40 916	37 362
2022	5	20	8,5	13 643	11 374	10 534	8 445	8 492			214 351	202 771	190 247	177 721	163 123	148 861	135 210	122 579	110 249	98 683	87 967	77 446	67 347	58 313	50 590	44 640	40 887
2022	5	21	9,0	15 383	12 890	11 997	9 680	9 733	7 383			210 887	198 133	185 590	170 697	156 127	142 000	129 271	116 611	104 710	93 655	82 770	72 289	62 879	54 809	48 566	44 614
2022	5	22	10,0	17 329	14 598	13 622	11 059	11 104	8 484	7 366		219 366	206 383	193 652	178 472	163 604	149 327	136 111	123 129	110 900	99 514	88 275	77 419	67 618	59 209	52 674	48 526
2022	5	23	11,0	19 457	16 479	15 411	12 583	12 600	9 700	8 451			214 812	201 820	186 363	171 205	156 628	143 000	129 769	117 221	105 514	93 930	82 708	72 502	63 761	56 942	52 603
2022	6	24	12,0	21 764	18 531	17 358	14 248	14 245	11 051	9 663	7 366			210 052	194 328	178 890	164 026	150 083	136 491	123 638	111 621	99 703	88 127	77 498	68 436	61 343	56 816
2022	6	25	13,0	24 240	20 750	19 457	16 049	16 045	12 542	11 009	8 451	7 359		218 297	202 320	186 616	171 474	157 130	142 000	130 107	117 794	105 556	93 637	82 567	73 199	65 840	61 133
2022	6	26	13,4	26 874	23 123	21 696	18 008	18 004	14 182	12 496	9 653	8 418			210 289	194 331	178 928	164 151	150 003	136 582	123 988	111 445	99 200	87 800	78 132	70 510	65 626
2022	6	27	13,8	29 647	25 639	24 106	20 131	20 127	15 977	14 116	10 966	9 585	7 334		218 183	201 987	186 334	171 301	156 889	142 000	130 326	117 484	104 918	93 193	83 231	75 350	70 291
2022	7	28	14,2	32 599	28 330	26 690	22 422	22 396	17 911	15 860	12 396	10 846	8 356	7 350		209 758	193 863	178 579	163 906	149 946	136 805	123 670	110 790	98 747	88 494	80 361	75 126
2022	7	29	14,6	35 729	31 199	29 450	24 886	24 792	19 973	17 728	13 926	12 288	9 537	8 441		217 644	201 509	185 980	171 051	156 831	143 000	130 000	116 811	104 457	93 920	85 536	80 129
2022	7	30	15,0	39 039	34 246	32 389	27 500	27 317	22 164	19 703	15 663	13 916	10 878	9 675	7 383		209 274	193 503	178 324	163 847	150 181	136 472	122 981	110 247	99 436	90 812	85 238
2022	7	31	15,0	42 529	37 472	35 475	30 237	29 941	24 457	21 916	17 603	15 725	12 383	11 053	8 493		217 152	201 035	185 618	170 893	156 977	142 000	129 215	116 054	104 985	96 129	90 398
2022	7	32	15,0	46 161	40 845	38 679	33 102	32 846	27 012	24 362	19 742	17 710	14 048	12 573	9 728	7 376		208 496	192 852	177 893	163 741	149 502	135 442	121 897	110 580	101 504	95 620
2022	8	33	15,0	49 897	44 328	42 002	36 057	36 020	29 818	27 032	22 075	19 864	15 870	14 220	11 077	8 453		215 921	200 060	184 879	170 500	156 014	142 000	127 700	116 149	106 865	100 837
2022	8	34	15,0	53 741	47 926	45 401	39 311	39 442	32 861	29 912	24 585	22 165	17 829	15 983	12 534	9 626	7 290		207 147	191 757	177 165	162 447	147 872	133 949	122 154	112 650	106 470
2022	8	35	15,3	57 644	51 591	49 128	42 849	43 090	36 123	32 983	27 247	24 590	19 910	17 836	14 078	10 879	8 244		214 757	199 145	184 326	169 361	154 523	143 000	128 541	118 809	112 471

Figure 64 Illustration of different fish groups growth and biomass until harvest weight 3,5 kg is reached.

Here smolt groups are entering the tank farm every 14 days, in a year this is 24 fish groups. The number in the cells are the biomass live at weekly intervals. The first smolt groups is harvested as 214,9 MT after 53 + 10 weeks- sum 63 weeks. The next groups shows very similar biomasses ranging from 214 MT up to 219 MT. Red number are the live biomass at harvest when 3,50 kg live weight is reached. Each tanks is then cleaned and new groups are entered after 2 weeks fallow period. This is an ongoing process leading to none fish harvested the first year, good biomass the 2nd, and a steady stage level in the 3rd and 4th year. The biomass profile could be any volume, here it is fish group each illustrated as 64 000 smolt every 14 days.

Below is an illustration where the different smolt number must be released to farming units for all 3 platforms to reach the same biomass at harvest- all with average weight of 3,5 kg per rainbow trout.

2 Productioni planning fish farming

Summery biomass potential large rainbow trout

- The illustrated pages above may result in;

	Open nets	Landbased tanks	Floating bags
500 MT biomass;			
Stocking no smolts	165 000	150 000	150 000
Smolt entry period	1 Apr-1 Nov	year round	year round
Fallow period per site	yes 3 months	none	yes 3 months
1 500 MT biomass			
Stocking no smolts	495 000	450 000	450 000
2 500 MT biomass			
Stocking no smolts	825 000	750 000	750 000
5 000 MT biomass			
Stocking no smolts	1 650 000	1 500 000	1 500 000

Figure 65 Elements for fish farming planning.

The advantage by introduction rainbow trout to the West region is the fact that salinity of the seawater is only a fraction of what is found in the Kattegat/North Sea region- levels are often within 5-10 psu (per mill), which act as a barrier for the sea lice. Experts in the West region confirm that this is the case, in addition the rainbow trout is more resistant against sea lice infection.

The rainbow trout is also best suited under these low saline conditions.

Local and international fish farming initiatives should exploit the potentials in the West Estonia region where the nutrient flux challenges must be consider. All modern land based fish farms do operate where mechanical filtering of the waste is a foundation of their licenses. There should be none differences for the West region.

This means that traditional Open net farming also with proper fish feed and a good fish health is well adapted, however the fluxes are here larger per kg fish produced.

West Estonia should grant farming licenses approx. i.e. 5x for an initial modern phase for i.e. 10 years period where agencies from Estonia (environmental, fish health, food safety) are involved, controlling and monitoring the progress over time and support with corrective action. Such permits should be granted with flexibility- if periods show performances in conflict of the Water Act and more precise to yearly flux quota issued per location, this should be observed and corrective actions should be implemented. Should the case be that some of the illustrated fish farming platform listed in this report do show advantages- then supports should be given to further expand such biomasses as long as onsite threshold targets are remained.

An important principle should be that any yearly waste fluxes should act equal regardless of the platform chosen by the private stakeholders, as long as one consider individual locations.

Setup with flux reduction per kg fish produced should then be allowed to produce a larger biomass compared to a situation where they rather chose a platform with a higher flux ratio per kg fish produced. The importance is that the total flux is to be specified per sites & zone are maintain regardless of platform in use. The authorities must be careful so that they are not directing the technology development or is putting them in a responsible position.

The same situation is for fish farmers on land- the quantity use of seawater per kg fish per year should be the outcome of the technical system chosen by the stakeholders- it is wrong to address permits where the total yearly sea water volume is specified- it is not the sea water volume that caused fluxes to the sea- it is the dissolved and bounded nutrient that is the main factor, example is the permit given for the on land fish tanks at Kesknõmme with a 99 million m^2 sea water volume per year.

It is the private stakeholders who should select the system in use, its complexity, capex and open level- the authorities should motivate and monitor.

Important is also that the West Estonian authorities motivate initiative setup on a larger volume scale so that all related parties can establish an economy of scale activity. We strongly recommend not to issue many too small licenses, group them together and issue less quantity of licenses. Some licenses should be small, medium and large. According to the location`s capability to recover after a farming period- this is positive as then various stakeholders can select among a variation among dimensions, capex availability and willingness.

In line with this a private/ public marine service/ process laboratories/ education centre and supporting lab, value added activity on land is crucial for both the finfish, fish health, macroalgae and shellfish initiatives being part of this report.

Our suggested aquaponic arrangements should attract wind driven energy companies in joining forces with production/farming stakeholders (energy is required for waterflow, production of oxygen, fish processing line, cultivation of macro algae and shellfish). Energy companies should also look into the possibility where their floating offshore wind platforms could be adapted to also facilitate farming units- fundament here i.e. integration of oxygen production and storage, fish feed transport and storage, facility for farming crew and shared service/ maintenance staff and facilities and crew/ships..

There is valuable supporting industry already in the Estonia coastal zone that certainly can support and participate in the illustrated aquaponic and fish producing arrangements;

- combination of wild fish processing/ gear production and maintenance- linked to fish farming mooring and net production and net services
- food safety, packaging, freezer and cooling facility and logistic
- in the Baltic/Nordic region there are multiple suppliers of various egg breeding program for trout, smolt, fish feed manufacturer
- Norway which is currently leading the technical development of new farming platform could certainly be an important supplier

B Aquaponic integration: the cultivation of shellfish blue mussel (*Mytilus edulis/trossulus*)

Farming mussels

Mussels are usually farmed above the seafloor. Farms typically consist of different floating substrates which are hung in the water column and attached to the seabed using weights. Often these cultivation substrates are smooth (e.g. 0.5−1 cm thick nylon ropes), looped (e.g. Donaghys ROM 1407 − Aqualoop Crop HM Rope) or ribbon-shaped ropes (e.g. Swedish bands). Trawling nets are also often used. Farming mussels by floating substrates is thought to be the most efficient method because predators cannot reach the mussels and the growth rate of mussels is high as in the upper water layers food is more plentiful and temperatures are higher.

Improving the environment through shellfish aquaculture has received increasing attention in recent years (Gren et al., 2009; Higgins et al., 2011; Kotta et al., 2020). Shellfish farms extract 25 times more nutrients from the environment than wetlands of the same area (Lindahl & Kollberg, 2009). Filter feeding mussels remove large amounts of planktonic microalgae from the water mass and thereby accumulate a significant fraction of nutrients in their bodies and/or channel the remaining nutrients to bottom sediments (Officer et al., 1982; Reeders & Bij de Vaate, 1990). Moreover, nutrients that settle to the bottom may be completely removed from the marine system: nitrogen compounds may volatilize to the atmosphere as molecular nitrogen (N_2) as a result of bacterial life (denitrification), while phosphorus compounds may leave the cycle due to burial in sediments (Conroy et al., 2005; Newell et al., 2005). As a consequence, adverse symptoms of eutrophication are expected to be reduced. At local scales shellfish farms can be also used to reduce the environmental impact of fish farming in both marine and terrestrial farms (Zhou et al., 2014).

Farming native blue mussel represents a vast yet untapped potential for eutrophication mitigation in the Estonian coastal waters. Mussels filter the water and remove suspended microalgae or phytoplankton. As a result, the water becomes clearer (Newell, 2004). However, such negative effects are highly unlikely as shown by the recent INTERREG project BBG (https://www.submariner-network.eu/balticbluegrowth). Farmed blue mussels need no additional nutrients for effective growth. Instead, they feed on water microalgae and the positive effect of filtration by mussels on water quality is immediate. Importantly, subsequent harvesting of farmed mussels removes a significant amount of nutrients from the marine environment and thereby constitutes a sustainable, low-impact, circular and potentially cost-effective measure for eutrophication control. In addition to reducing eutrophication, mussel shells consist of mineralized carbon and mussel farming is a means to permanently remove carbon dioxide from the air, thus helping us to reach greenhouse gas targets. Preliminary research has shown that the predicted total area of farms needed to achieve nutrient reduction targets is attainable under the current maritime spatial planning environment in the Baltic Sea. Nonetheless, the actual sea space for mussel farms should be allocated carefully to avoid unacceptable environmental impacts or conflicts with other uses. The use of appropriate farming technology and harvesting, which is designed for the smaller and slower growing Baltic Sea mussels, provides remarkable production rates, cost-effectiveness, and also better nutrient content in the yield (Loite and Kotta, 2021).

Applying relevant farming methods for the blue mussel is a profitable and sustainable way to remove nitrogen and phosphorus from the Baltic Sea and to capture excess atmospheric carbon. Mussel farming not only provides a tool for nutrient mitigation, but also contributes to the social and economic sustainability of rural areas. Furthermore, farms are seen as a restoration measure to supplement natural mussel reefs lost to anthropogenic impacts. When available in a sufficiently large amount, mussels can provide a new sustainable protein resource for animal feed and the food industry or serve as a biological alternative to chemical fertilizers. Mussel meal is a good raw material and feed ingredient with no detriment to the growth and health of chickens. Sustainably produced blue mussels have a growing market because of their expanding field of application in different industries. In addition to animal feed and human consumption, a range of valorisation options exist for mussel meat and shells. Mussels are known to be a reserve of valuable compounds such as bioactive proteins, minerals, pigments, enzymes etc. This leads to a solid potential to use these components to produce high value food supplements, biocosmetics, and so on (Loite and Kotta, 2021).

The results of the BBG (Baltic Blue Growth) project (https://www.submariner-network.eu/balticbluegrowth) showed that farming mussels is both efficient and economically feasible for Estonia. The environmental assessment conducted on all six mussel farms on the Baltic Sea failed to detect any negative environmental impact. The environment may be negatively impacted by the establishment of very large mussel farms (area > 1 km^2) but existing technological solutions prevent us from establishing farms of that size. In addition to the aforementioned, the toxicity of Estonian mussels is very low. Mussels grown here can be used both as food and/or feed.

Only two mussel species live in the Estonian marine area: *Mytilus edulis/trossulus* and *Dreissena polymorpha*. The distribution areas of these mussel species are very different due to very different environmental requirements of these species. This is why a selection of the cultivation areas of these mussel species should be made very carefully to avoid suboptimal habitats. In the optimal habitats, however, appropriate species will attach to the cultivation substrates and farm yields are relatively stable between years.

Mytilus edulis/trossulus is the most important mussel species for Estonian aquaculture. Blue mussel farming relies on recruitment of free-swimming larvae (veligers) from wild populations that are entrained into the water column and passively dispersed from natural mussel reefs. After dispersal, veligers attach themselves to available substrates, including objects in the water column, e.g., mussel farms. This is normally happening once a year, in the late May or the early June. Thus, determining how to best allocate areas suitable for mussel farming requires consideration of (1) the connectivity between candidate farm sites and natural mussel reefs in order to define areas that do not require artificial mussel seeding and (2) the production potential of mussels in candidate farm sites. A typical Baltic Sea mussel farm has an area of a less than 5 hectares and consists of 25 km of rope suspended at different depths. Cost effectiveness of the farms is dependent on nutrient and salinity levels as well as the type of equipment for culturing mussels, with specialized ropes that optimize veliger recruitment being the most effective for culturing the small mussels found in the Baltic Sea. The growth cycle of this mussel in farms in Estonian coastal waters is 1.5-2 years. The modelling of the production yield of *M. edulis/trossulus* showed that for the majority of the West Estonian sea areas the production of mussels exceeds 1.5 kg mussels per m rope which equals approximately to 80 tonnes of mussels per ha per harvest (Fig. X; Kotta et al., 2020).

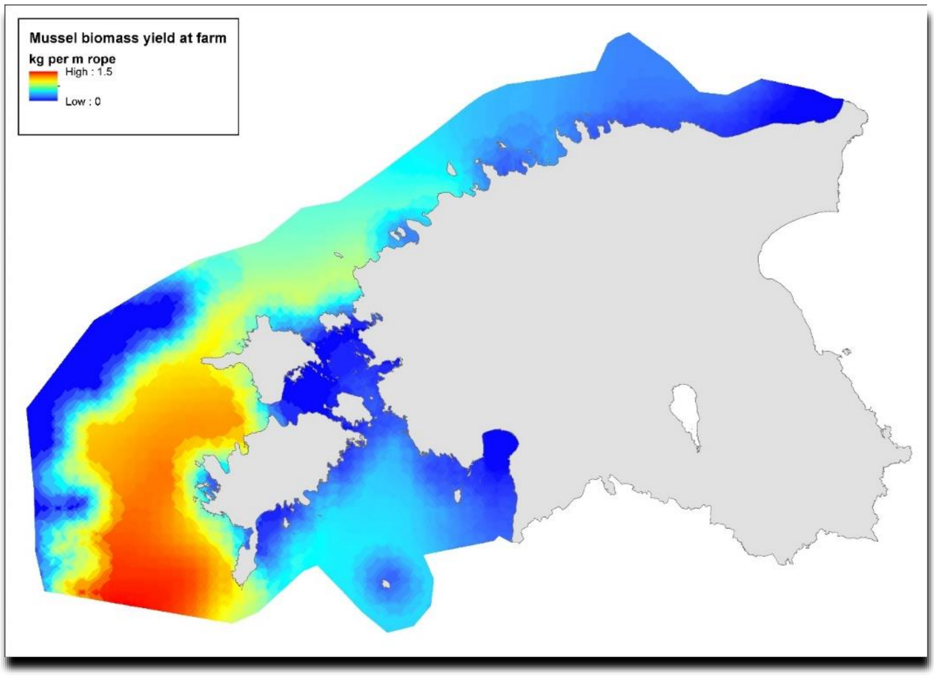


Figure 66. Modelled production potential of mussel farms in Estonian marine areas (kg wet weight per m^{-1} rope and harvest) (Kotta et al., 2019).

Comments

Mussel farming is site-specific and the use of the right growing substrates ensures higher yields (i.e. economic success). In order to achieve optimal farming technologies, it is necessary to test the potential of different substrates in good growing areas and to select the best technological solutions for Estonia (or a specific water body).

Aquaponic system for shellfish for this report

Modelling the clearance rate of *M. edulis/trossulus*

In order to define an effective aquaponic system, which cleans the wastewater of fish farms, the knowledge on the filtration potential of mussels needs to be known. The effectiveness of filtration of mussels depends on several factors, such as shell size, water temperature, salinity, water movement and concentration of suspended solids. Importantly, relationships between these environmental variables and the filtration rate are highly location-specific (Petersen & Loo, 2004; Lauringson et al., 2007, 2009, 2014; Kotta et al., 2009).

In this project, we combined all the experimental measurements collected in previous regional projects covering the West Estonian area into a single aggregated database to model the clearance rate of *M. edulis/trossulus*. Data on the clearance rates of the Estonian *M. edulis/trossulus* were obtained from the following scientific papers and associated databases: Kotta & Møhlenberg (2002), Kotta et al. (2005), Lauringson et al. (2009), Lauringson et al. (2014).

Modelling algorithms. The contribution of different environmental variables on the filtration rate of *M. edulis/trossulus* was explored using the Boosted Regression Trees technique (BRT). BRT models are capable of handling different types of predictor variables and their predictive performance is superior to most traditional modelling methods (see e.g. comparisons with GLM, GAM and multivariate adaptive regression splines, (Elith et al., 2006; Leathwick et al., 2006). Overfitting is often regarded as a problem in statistical modelling but can be overcome by using independent data sets. The BRT modelling iteratively develops a large ensemble of small regression trees constructed from random subsets of the data. Each successive tree predicts the residuals from the previous tree to gradually boost the predictive performance of the overall model (Elith et al., 2008). Important parameters in building BRT models are the learning rate and tree complexity. The learning rate determines the contribution of each tree to the growing model and tree complexity defines the depth of interactions allowed in a model. A tree complexity of 1 assesses only main effects; A tree complexity >1 includes interactions. Different combinations of these parameters may yield variable predictive performance but generally a lower learning rate and inclusion of interactions gives better results (Elith et al., 2008). In the current study, the model learning rate was kept at 0.001 and tree complexity at 5. Model performance was evaluated using the cross-validation statistics calculated during model fitting (Hastie et al., 2009). The BRT modelling was done in R using the gbm package (Elith et al., 2008). Standard errors for the predictions and pointwise standard errors for the partial dependence curves, produced by R package "pdp" (Greenwell, 2017), were estimated using bootstrap (100 replications). Multicollinearity can be an issue with BRT modelling when assessing if and when environmental variables are of ecological interest. Thus, prior to modelling, the Pearson correlation analysis between all environmental variables were calculated in order to avoid including highly correlated variables into the model. The correlation analysis showed that most variables were only weakly intercorrelated ($r < 0.5$).

Key results. BRT models on the clearance rate of *M. edulis/trossulus* accounted for a significant proportion of the variability with r^2 values estimated at 0.93. Salinity was the best overall predictor in the model of clearance rate. Other important variables were water temperature and the concentration of organic particles in the seawater.

Increasing salinity increased the clearance rate of *M. edulis/trossulus* individuals up to a certain threshold value (i.e. 5 psu). The temperature response was more gradual with increasing temperatures resulting in increasing clearance between 0 and 25 °C. The clearance rate was inversely related to the content of organic particles. Importantly, in order to maintain an effective filtration by mussels, the concentration of organic particles should be kept below 2.5 g m^{-3} (Figure 67). In order to extrapolate the clearance rate of mussel individuals to the population scale, we established allometric relationship between mussel length and weight using mussels collected from the western parts of the Estonian maritime areas (Figure 68).

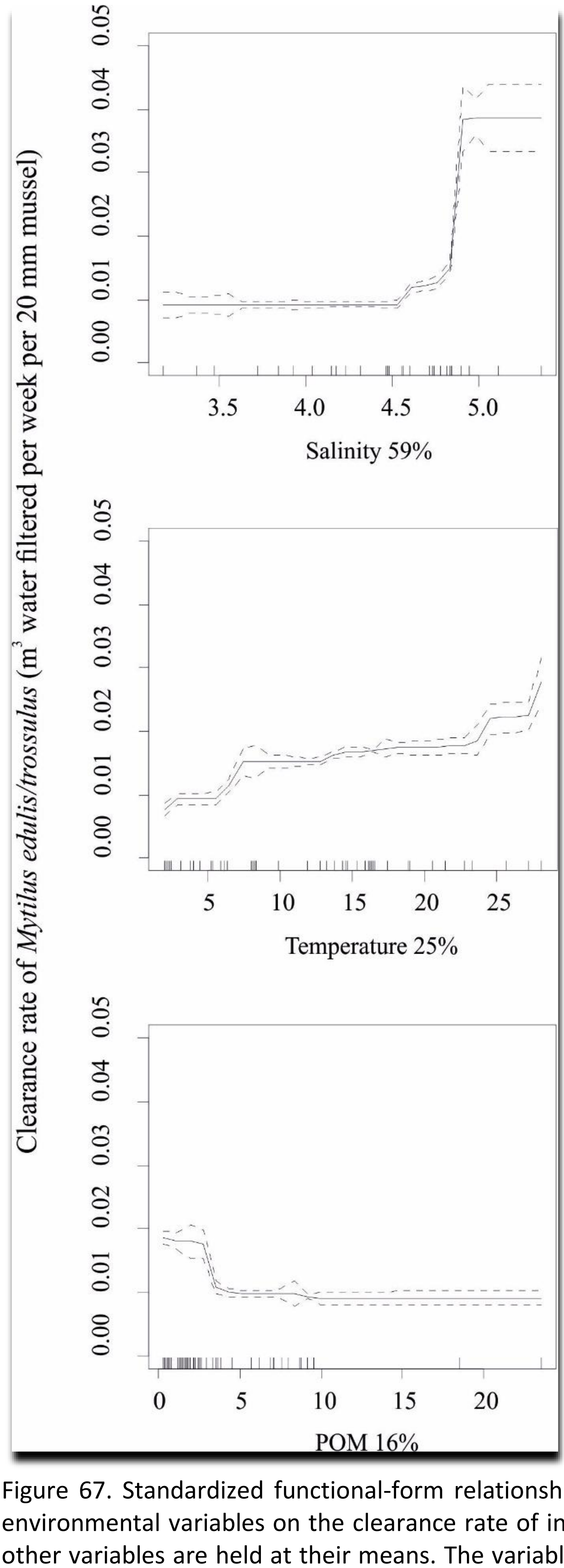


Figure 67. Standardized functional-form relationships (± Standard Error) showing the effect of key environmental variables on the clearance rate of individual mussels of *M. edulis/trossulus*, whilst all other variables are held at their means. The variables is ordered by their relative contribution in the BRT model (shown in %). Upward tick marks on x-axis show the frequency distribution of data along this axis.

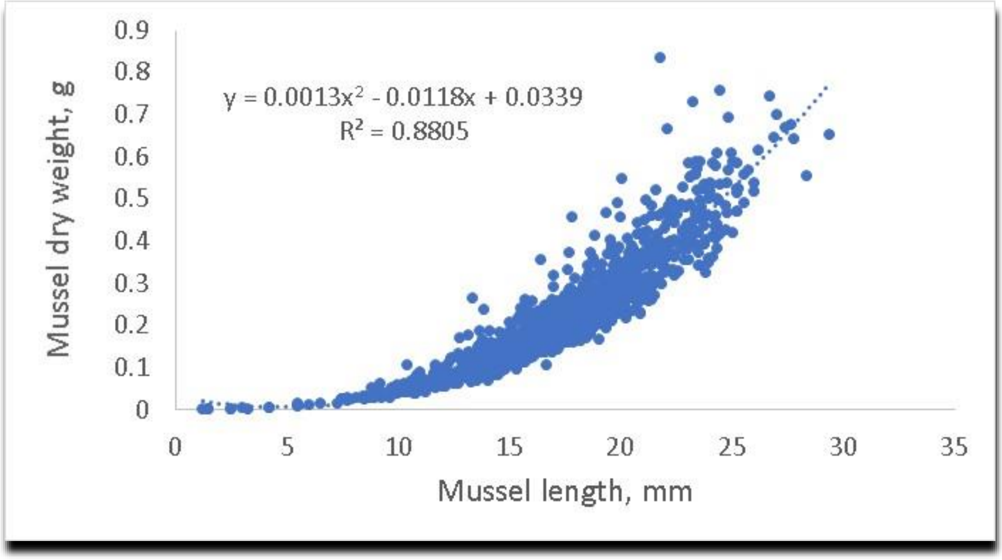


Figure 68. Relationship between mussel length and weight in Estonian marine areas (unpublished data).

Using mussel aquaponic units to clean the wastewater of land based fish farms

It is important to notice that in our base calculation of fish production, biomass, feed and waste volumes we used one of many potential mix of smolt entry. The listed values of production capacity of mussel, macroalgae is not directly transferable to other production setup. Our numbers are only relevant for our dimensions of tanks and fish bags and also our average density of kg fish/m^3 enclosed water, time of year and their feed volume per day, per week.

The trawl nets dimensions and the macroalgae density in the water column of the algae bags are other important parameters that certainly influences the aquaponic effectiveness of capturing fluxes.

Our baseline setup: Aquaponic unit installed in sea (mussel bags)

The aquaponic system is installed at sea in the vicinity of the land-based fish farm. Effluent from the fish farm is channelled by pipeline to a mussel aquaponic unit. Importantly, nutrients do not leak out from such a system into the marine environment. Our mussel aquaponic unit has the following dimensions: diameter 28 m, depth 10 m, surface area 615 m^2 and volume 6154 m^3. Each of such mussel aquaponic unit includes trawl net as a substrate for mussel growth. Each trawl net element has 9 x 13 m in size, the trawl nets are arranged in series, the distance between trawl net elements is 25 cm and such an arrangement results a total of 6552 m^2 of growth substrate for mussels in the aquaponic system. There is a pump at the bottom of the mussel aquaponic station that daily removes mussel faeces and dead shells settled at the bottom.

In order to develop sewage treatment schemes for fish farm effluents based on shellfish culture (i.e. a mussel aquaponic unit) and to assess the efficiency of such a system we applied the model of clearance rate on the estimated dynamics of effluents originating from an hypothetical fish farm (Figure 69). In order to clean up all the effluent originating the fish farm, seven (minimum 6 and maximum 9 units) such shellfish units need to be set up (Figure 70). Even though at some seasons a lower number of mussel units can purify all the effluents, it is not practically feasible to change the number of such treatment units seasonally.

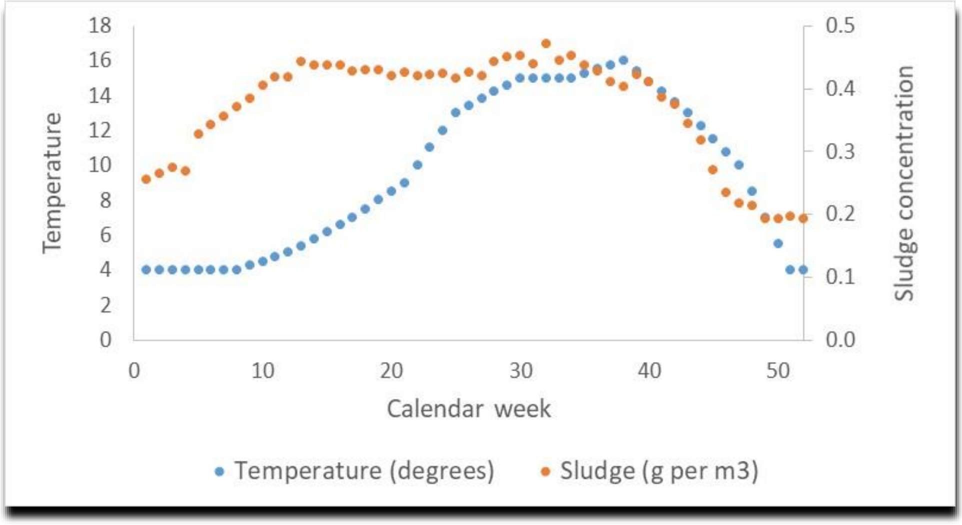


Figure 69. The dynamics of water temperature and sludge concentration in the sea based aquaponic mussel unit within one calendar year, for our baseline fish farm.

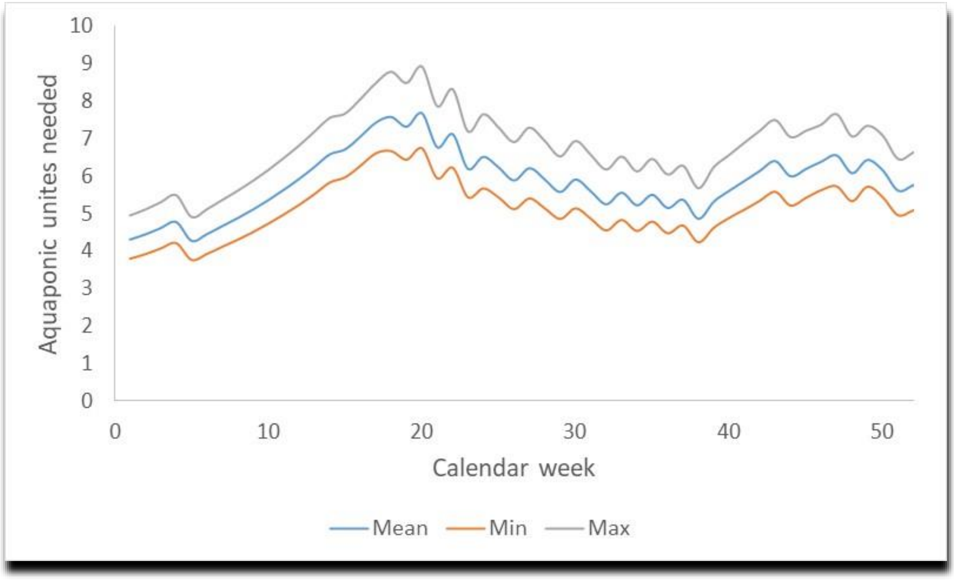


Figure 70. The number of sea based aquaponic units needed to filter out 100% sludge coming from the drum filter within one calendar year for our baseline fish farm.

In order to set up such purification stations, the trawl net must first be placed in the marine environment in May-June. These nets must then be inspected to see whether the juveniles of the shellfish have attached to the net. If successful, the nets can be moved to the aquaponic system. It takes about nine months for the shellfish to grow, at which point such a mussel treatment unit is ready to receive the fish farm effluent at full potential. Such a treatment plant can work for years without being harvested. However, if the aim is to harvest shellfish, it is most reasonable to do this when the shellfish are 2.5 years old. The expected mussel yield of each aquaponic unit is in minimum 47.9 tonnes wet weight of mussels (flesh and shell) per harvest (i.e. for a period of 2.5 years), or said 24 tonnes per year. Mussel harvesting should be preferably taken place in autumn when the biochemical composition of the mussels is at its best and when the amount of fish farm effluent is not the highest.

<u>Aquaponic unit installed on land (tanks on land)</u>

Alternatively, mussel aquaponic units can be installed on land. Here, the mussel unit has the following dimensions: diameter 25 m, depth 4.5 m, surface area 491 m^2 and volume 2208 m^3. Similar dimensions as for our baseline biomass for fish farmed on land.

As for sea-based system, each of such mussel aquaponic unit includes trawl net as a substrate for mussel growth. Each trawl net element has 4 x 11 m in size, the trawl nets are arranged in series, the distance between trawl net elements is 25 cm and such an arrangement results a total of 2112 m^2 of growth substrate for mussels in the aquaponic system. There is a pump at the bottom of the mussel aquaponic station that daily removes mussel faeces and dead shells settled at the bottom. There are different average density of fish per enclosed m3 for bags versus fish tanks.

In order to clean up all the effluent originating the fish farm, 24 (minimum 21 and maximum 28 units) such shellfish processing plants need to be set up (Figure 72). The expected mussel yield of each aquaponic unit is in minimum 15.4 tonnes wet weight of mussels (flesh and shell) per harvest (i.e. for a period of 2.5 years).

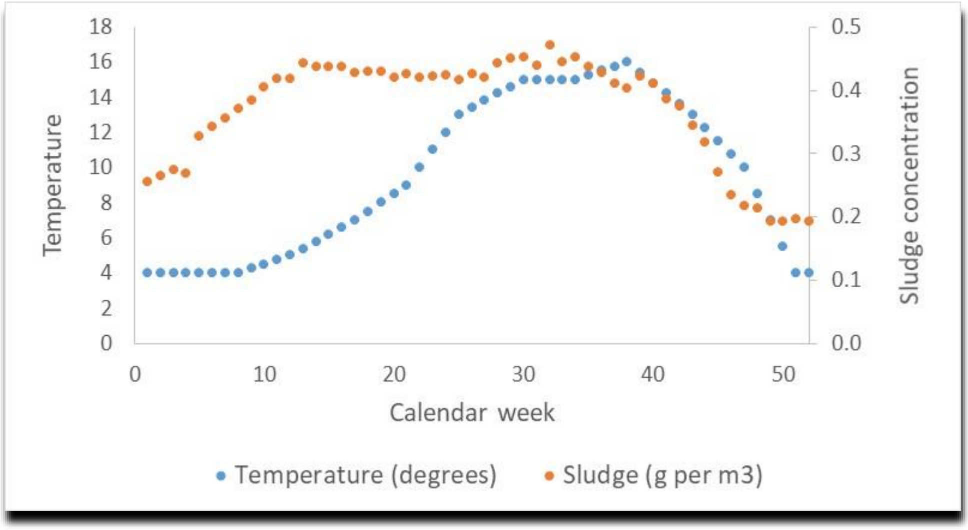


Figure 71. The dynamics of water temperature and sludge concentration in the land based aquaponic mussel unit within one calendar year.

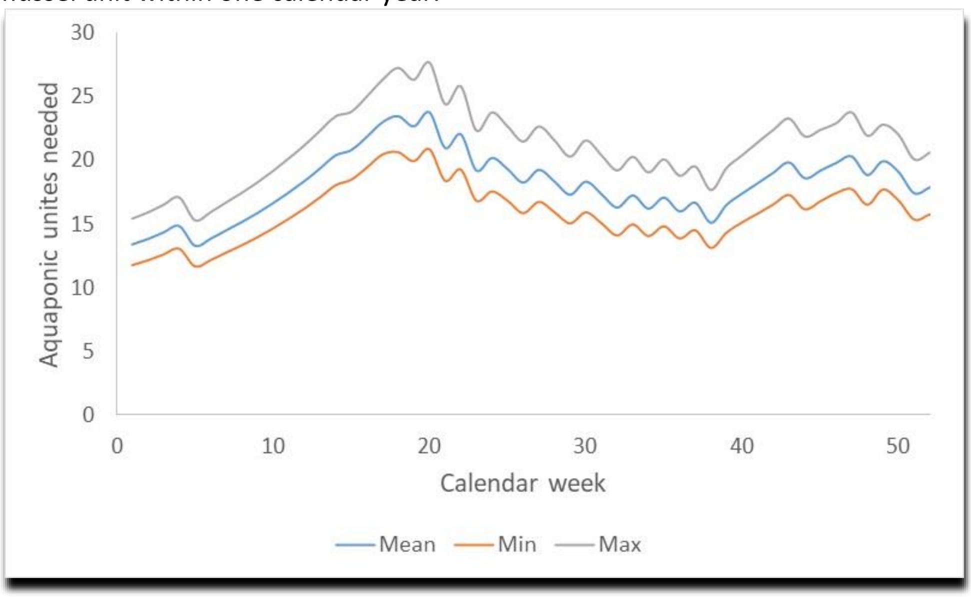


Figure 72. The number of land based aquaponic units needed to filter out 100% sludge coming from the drum filter within one calendar year.

Using mussel aquaponic units to clean the wastewater of Open net fish farm

Similar aquaponic system (mussel bags) as described above for the land-based fish farms can be used in the Open net solution. Here, it is important to assure that nutrients do not leak out from such a system into the marine environment. Moreover, it is important to assure the maintenance of a pump at the bottom of the mussel aquaponic station that daily removes mussel faeces and dead shells settled at the bottom.

The actual number of such mussel aquaponic stations will depend on the temperature regime in a given sea area, but in general the Open net areas of west Estonia are characterised by a similar seasonality of temperatures as described above for the land-based system and therefore the expected number of mussel aquaponic units do not significantly deviate within the entire area of interest of west Estonia and is estimated at 7 ± 2 mussel units per fish farm.

Offshore shellfish cultivation

In addition to offsetting the impacts of fish farming, shellfish farms can be independently established over a very large area, and in essence, there is an unlimited natural resource (microalgae) for this activity. Besides nutrient removal, such a shellfish farm significantly increases water transparency and mitigate the risks of local algal blooms within a radius of about 1 km^2. Consequently, it makes sense to locate shellfish farms in areas experiencing land-based nutrient load, as such co-existence can compensate for the nutrient fluxes released into the sea and keep the water in the vicinity of wastewater outlet pipe transparent. Information on the suitability of different marine areas for shellfish farming can be found on the ODSS portal at http://www.sea.ee/bbg-odss/Map/MapMain. The same portal (see section plan your farm) shows the production yield of mussel farms in a given sea area as well as the expected removal of nutrients following the mussel harvest.

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C Aquaponic integration - cultivation of macroalgae

Introduction

Macroalgae have a long history of exploitation by peoples all around the globe (Periera, 2016). Primarily utilised as a food source, edible seaweed provides a good source of proteins, lipids and dietary fibres when consumed by humans (Dawczynski et al., 2007; Macartain et al., 2007).

Macroalgae's high photosynthetic productivity also implicates it as an important source of carbon storage globally. As macroalgal material is sequestered into sediments and exported into the deep marine environment, it locks away atmospheric CO2 and acts as a carbon sink (Gao & McKinley, 1994). Additionally, collecting or cultivating macroalgae for use in the production of fuels can act to offset anthropogenic atmospheric carbon production from fossil-based fuels by providing an alternative fuel source in the form of carbon neutral biofuels and bio-butanol (Enquist-Newman et al., 2014; Kraan et al., 2013; Potts et al., 2012; Wei et al., 2013). In addition to the capture of CO2, macroalgae uptake dissolved inorganic nutrients such as nitrogen and phosphorous. This process stimulates algal growth and is important in mediating the deleterious effects eutrophication has in coastal zones, which as it stands, represents a major issue for many coastal regions around the globe (Leandro, 2019).

Macroalgae cultivation is primarily dependent upon seawater containing sufficient nutrients to act as a growth medium. As a photosynthetic organism, macroalgae growth rates are determined upon environmental factors such as temperature, nutrient availability, pH, CO2, solar radiation and salinity (Dawes et al., 1998; Choi et al., 2010; Guo et al., 2015). However, such factors combine in a complex interplay to determine a given growth rate dependent on the macroalgae species under cultivation, of which each species is unique. Furthermore, as many algal species display complex and poorly understood life stage histories, the factors that control both germination and growth likely change through time adding to the complexities of cultivation and maximising production (Cumming et al., 2019).

Suitable species for cultivation in NE Baltic Sea

As Baltic Sea is a brackish environment most of the macroalgal species cultivated in the other parts of the world ocean can not survive in these conditions. Species suitable for cultivation should usually correspond to one or more of following criteria:

1. Opportunistic species with fast growth and high nutrient and CO_2 uptake
2. Generalists in substrate requirements
3. Effectively controlling epiphytism
4. Vegetative reproduction, simple life cycle
5. Tolerant to moderate mechanical disturbance

Total number of macroalgae native to Estonian coastline is up to 80 species with about 20 being most frequent. Out of them less than 10 can be selected based on listed criteria. Most promising candidate species for mass cultivation belong to group of green algae.

Chlorophyta (Green algae)

Chlorophyta or green algae so called due to the chlorophyll (a and b) pigments that give its appearance form a large group of photosynthetic organisms. Chlorophyta utilise these pigments along with carotenoids, not only for energy production but also to protect the damaging effects of ultra-violet light (Barsanti & Gualtieri, 2006) and as chemical defence (Kadam et al., 2013).

Chlorophyta have been shown to be a rich source of carbohydrates, particularly that of sulphated polysaccharide which are structured within the algal cell walls (Lahaye & Robic, 2007). One such polysaccharide, ulvan, derived from Ulvaceae is a water-soluble gelling polysaccharide with bioactive properties such as immunomodulating, antiviral, antioxidant and anti-cancer (Kidgell et al., 2019). Ulvans account for roughly 20-30% of the total carbohydrate component of chlorophyta but their bioactive concertation and function vary dependent upon factors that pertain its given chemical structure. Therefore, ulvan bioactivity is highly diverse and differs based on the species from which it is extracted from as well as the environmental factors effecting an individual plant (Kidgell et al., 2019). Ulvan is of interest to the biomedical industry, its potential use in applications related to tissue engineering, antibacterial biofilm prevention and as a drug delivery device have been noted by researchers once it was proven ulvan is recognised animal liver cells (Kidgell et al., 2019; Alves et al., 2013; Wijesekara et al., 2011; Venkatesan et al., 2015; Cunha & Grenha, 2016). The development of products related to such effects has the potential lead to significant economic opportunities.

In addition to ulvans unique gelling and bioactive properties, chlorophyta are reported to have novel uses outside of the food and pharmaceutical industries. Anionic polysaccharides found within Ulva sp. have the ability to accumulate heavy metals within the algal cell structure. As such, Ulva sp. can concentrate heavy metals found to pollute contaminated waters and when removed and destroyed can mediate pollution (Webster & Gadd, 1996; Bocanegra et al., 2009; Schijf & Ebling, 2010). This ability by Ulva sp., therefore can be utilised in the mitigation of anthropogenic wastewaters as the species display high growth rates particularly under high nutrient regimes (Kraan, 2013; Castine et al., 2013, Lawton et al., 2013; Glasson et al., 2017). Ulva propagation is therefore positioned as a useful tool for environmental managers for heavy metal bioremediation.

Overall chemical compounds derived from chlorophyta have been demonstrated to be highly diverse in nature with applications in pharmaceuticals, nutraceuticals, foods, feed, agriculture and bioremediation.

For Estonian coastal conditions species *Ulva intestinalis* is recognised to be one of the most perspective species for mass cultivation:

1. species is present in Estonian coastal sea most of the vegetative period (April November)
2. species can grow both in attached and free floating form
3. species is salinity tolerant (0,1-15 PSU)
4. species utilises high concentrations of nutrients
5. gives several generations during the vegetative season
6. active control of epiphytes
7. simple structure
8. simple life cycle (Figure 1.)
9. multitude of commercial applications

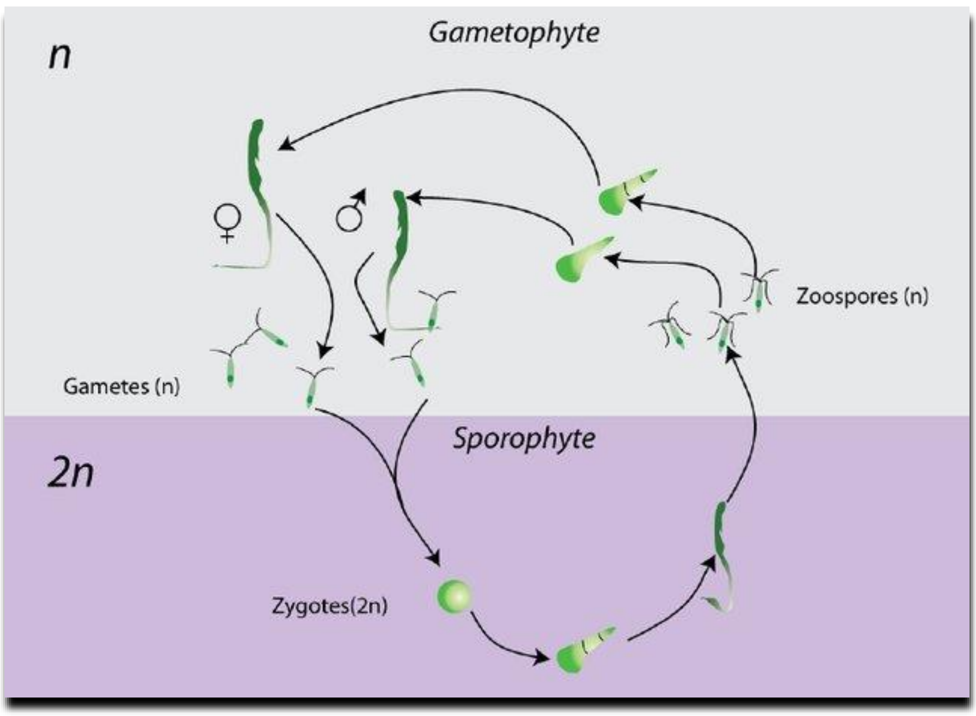

Figure 73. Life cycle of *Ulva intestinalis*. (from Bast 2014).

Methods of Cultivation

The cultivation of macroalgae is predetermined by the specific growth requirements of a given algal species. In general, the physical properties of seawater used as a cultivation medium are the main environmental factor regulating growth. Macroalgae growth is always regulated to varying degrees by the factors of temperature, pH, salinity, nutrient availability and solar radiation (PAR). Moreover, macroalgae often display complex lifecycles and as such certain environmental factors will affect algal growth disproportionality at varying life phases. Thus, a high degree of biological and technical knowledge is required for a cultivation venture to succeed.

Integrated Multitrophic Aquaculture

Traditional single species aquaculture whereby one species is cultivated in a manner that maximises biomass production is increasingly viewed as overly simplistic and one that contributes to environmental degradation of the marine environment. In order to mediate some of the environmental impacts associated with animal aquaculture, such as eutrophication from excess nutrients, the spread of disease, as well as improving farm output from a given area, seaweeds are being integrated into traditional animal aquaculture operations. The practice of co-farming multiple aquaculture species in close proximity is known as integrated multitrophic aquaculture (IMTA) and provides numerous benefits through the interconnection of species. The IMTA model prioritises cultivating species whose products (inorganic and organic) of one species are up taken by another to serve as an energy source. As such, the need for the addition of costly fertilisers to promote seaweed growth is reduced and profit is increased sustainably through seaweed biomass growth.

Several studies have assessed the effect fish aquaculture effluent and waste products has on the growth of macroalgae. These investigations found that seaweed biomass increased when cultivated within existing fish farms. A study by Buschmann et al., (2008) demonstrated that seaweed grown in close proximity to salmon aquaculture operations in combination with other filter feeders in an IMTA arrangement resulted in the uptake of, and absorbance of, organic and inorganic nutrients. Such an arrangement reduces the environmental impact of salmon farming operations (Buschmann et al., 2008).

Integrating macroalgae production into current animal cultivation methods may also benefit farm operations through bioremediation and other biological services. As macroalgae grow they uptake excess nutrients from the water column providing a filtering effect improving overall water quality and offsetting detrimental farm effects. Furthermore, macroalgae cultivation can offset environmental impacts on land. Through their use as a fertiliser to improve soil condition and substituting synthetic chemicals macroalgae can offset atmospheric emissions. The environmental benefits of macroalgae aquaculture are therefore felt both at a local and global scale with the mitigation of eutrophication and increased support of biodiversity acting locally, and carbon sequestration or 'blue carbon' acting globally. With this in consideration aquaculture operations can make use of environmental tax subsidies to improve their economic viability.

One of the greatest challenges with implementing IMTA into traditional single species aquaculture operations is identifying suitable seaweed species for culture. Typically, species high in productivity/growth rates i.e. high nutrient uptake, high in economic value and that are relatively hardy in regard to environmental conditions are most suitable for IMTA. By optimising farm design and utilising data driven models combined with primary biological research seaweed species can be selected for IMTA to optimise economic gain and environmental mediation.

By adopting IMTA practices, aquaculture operations have the ability to not only reduce their environmental impacts, but also gain economic benefit by diversifying products that can be commercialised and brought to market. Figure 2 provides an example of an IMTA operation.

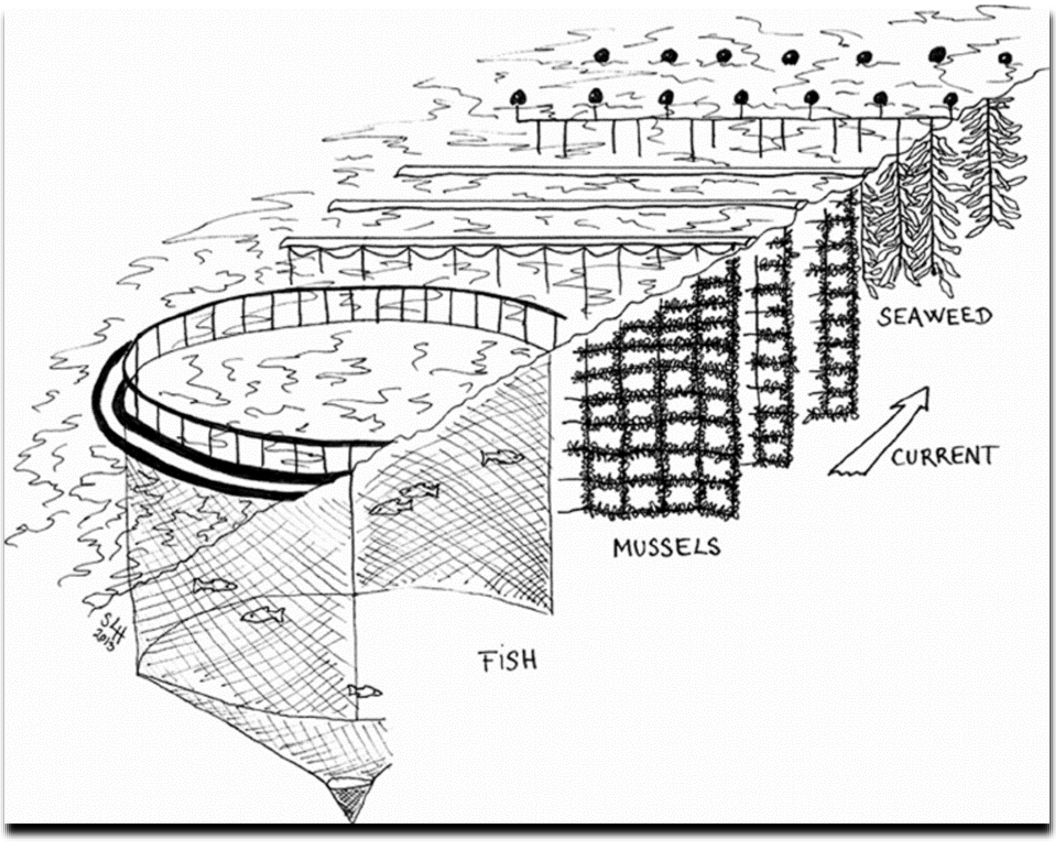

Figure 74. Schematic of an integrated multi-trophic aquaculture (IMTA) example of rainbow trout in a polar circle cage, mussels on a SmartFarm TM longline and seaweed suspended on droppers on longlines (Holdt & Edwards, 2014).

Cultivation of Ulva intestinalis

Ulva sp. is used for cultivation worldwide for a big number of different applications. This group of species is cultivated both free floating in tanks and on ropes in open water. Experiences with Ulva cultivation in Estonia are almost absent. Recently ended project was a first attempt for such cultivation and using of the Ulva biomass to remove nutrients from fish-farm effluents (TÜ EMI, 2021). During this project the main aim was to study the possibility of removing nutrients from fish farm wastewater before entering back to the sea but as a side product the maximum of 4% of gain in biomass daily was achieved in successful experiment (figure 3.). According to literature the biomass gain of Ulva in such systems can reach up to 30 %/day.

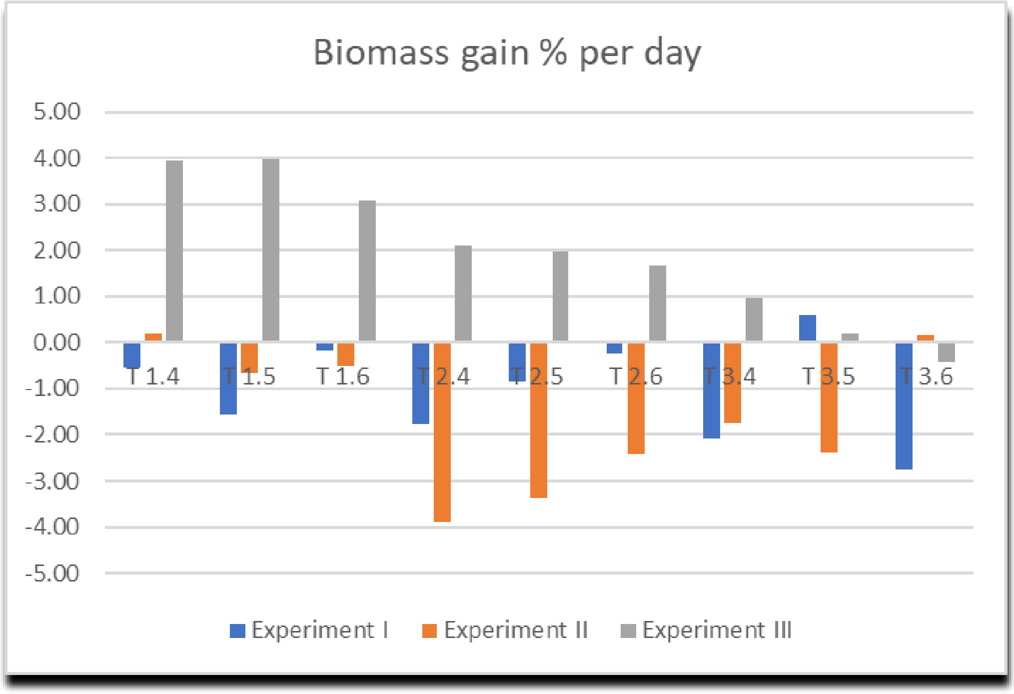

Figure 75. Biomass gain in incubation tanks (% per/24h) during the Ulva cultivation experiment carried out in Kesknõmme (NW Saaremaa island) in 2020. Each experiment lasted 4-5 weeks. Experiments I and II failed because of overheating of the water in incubation tanks (TÜ EMI 2021).

The concentration of the nutrients tested was found to decrease throughout the mesocosm series. Both Nitrite and Nitrate were observed to be up taken by the mesocosms containing the macroalgae Ulva intestinalis when compared to the associated control. Under favourable growth conditions U. intestinalis demonstrated a significant increase in the uptake of both nitrate and nitrite resulting in a decrease of 18.4% and 25.2% of the nutrients respectively when compared to the control series (students t-test; $p < 0.05$) (figure 4.). The phosphorous nutrient data was found to have a large degree of variability among the samples and due to this high variability, no significant difference between the control series and macroalgal stocked series for these nutrients was observed. Overall, the system demonstrated a high degree of nutrient removal efficiency, with up to 60% of both nitrate and nitrite removed from the system and 60% of phosphate and 30% of phosphorous also removed relative to concentration of nutrients measured in the trout mesocosm (Hall and Martin 2021).

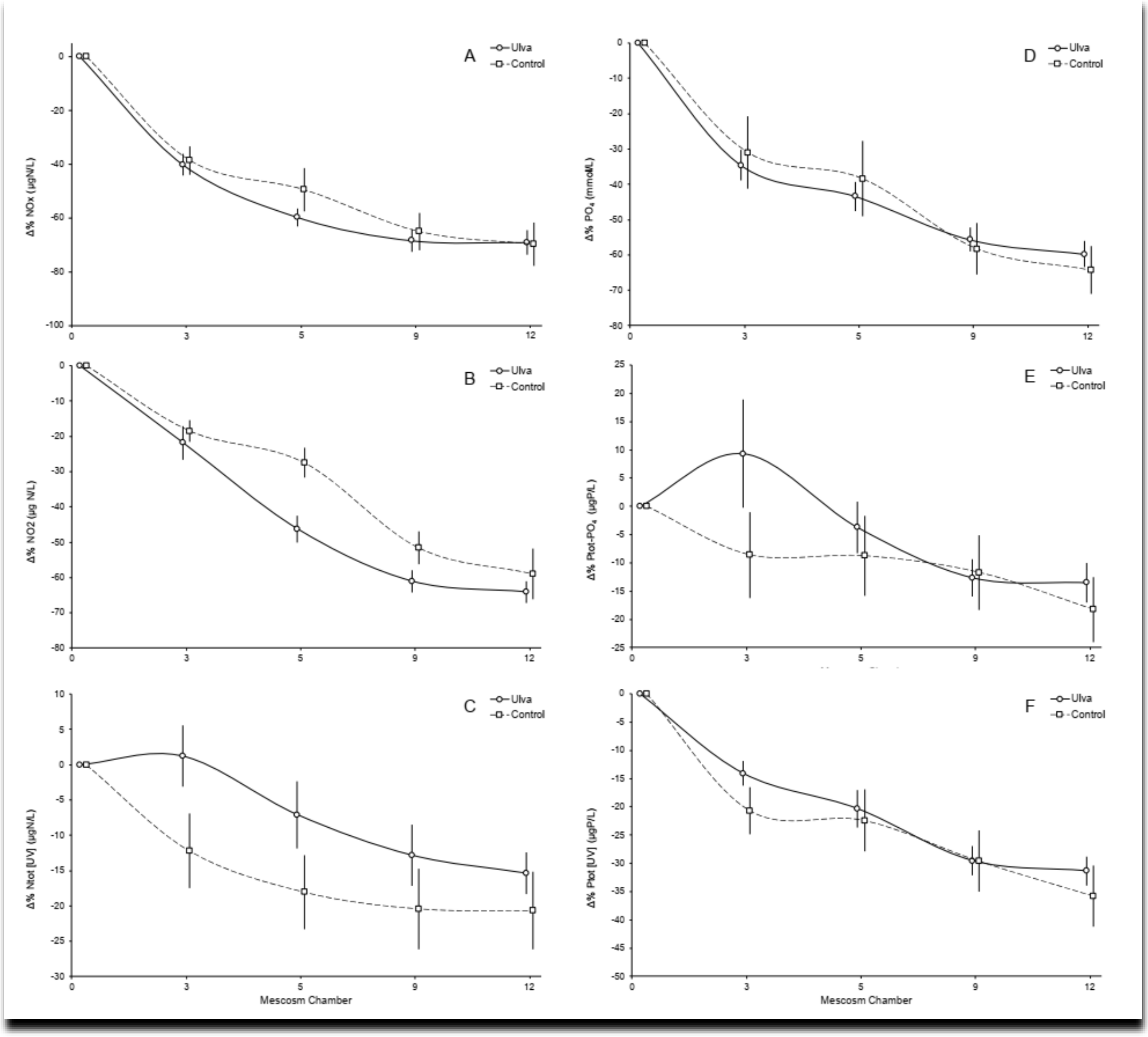

Figure 76. Change in the mean concentration of the nutrients (A= nitrite, B= nitrate, C= total nitrogen, D= phosphate E= phosphorus and F= total phosphorus) as a percentage relative to the initial trout stocked mesocosm across the mesocosm series. The mesocosms ranked four, five and six in the Ulva series were stocked with macroalgae. The control series contained no macroalgae. Error constructed as ±1 standard error (from Hall & Martin 2021).

Modelling Ulva growth potential for WE fish farm case

In our case we assume that we will be able to cultivate Ulva in the continuous flow of seawater coming from fish farm bags and mussel farm bags. Mussel incubation bags will remove most of the suspended solid and water entering Ulva bags will be saturated with CO_2 and having high concentration of nutrients. Water temperature will change with the season but we assume that farm will be located in the area with deeper water (not in the archipelago area where the water temperature can reach 20+ during the summer months). Temperature optimum for cultivation of Ulva should be in the range of 13-18 C (observation from TÜ EMI 2021). Temperatures higher and lower are considered as not optimal.

Modelling result is presented in Table 1. So we consider cultivation unit to be of volume 6154 m^3. Optimum density of Ulva in such unit is 1,6 kg dw/m^3. This density will result in close to 10 t of dry weight of Ulva kept continuously in the unit. For aeration and enabling circulation of algal material it is needed to continuously aerate the tank/bag so the vertical water circulation is created and algal mass is equally exposed to the sunlight. It is assumed that nutrient and CO_2 are available in optimum amounts (no limitation) and the productivity of biomass is estimated to be at 10% per day for 3 months and half of that for 5 months per year.

Key modelling observations;

- Nutrient content of Ulva sp. 30-36 mg/g dw for nitrogen and 1,2-1,8 mg/g dw phosphorus was used (Villares et al 1999).
- Result shows approx. 160 t of dry weight production of *Ulva intestinalis* for the one season per one tank/bag.
- Amount of nutrients removed from the effluents by generating this biomass is close to 4,8 t of nitrogen and 0,230 t of phosphorus.

Table 1. Results of productivity estimates for Ulva cultivation in WE fish farm setup.

Calculation for 1 bag	
density kg dw/m³	1.6
volume m³	6154
standing stock kg dw	9846.4
growth 1 day (10%)	984.64
growth 30 days	29539.2
growth 90 days (optimum)	88617.6
growth 150 days (50% of optimum)	73848
growth per season kg dw	162465.6
growth per season kg ww	1624656

Figure 77 Productivity data *Ulva intestinalis*

Possible restrictions:

1. biomass should be constantly harvested/removed from the incubation tank (at least once per 3 days 1/3 of the biomass should be removed during optimum season)
2. Starting biomass or generation G0 is needed to operate the incubation facility. This can not be harvested from the nature nor purchased – separate on land farming facility is needed.
3. This mass cultivation has not been done in practice – so the development and testing stage is needed before real-life application.

Figure 78. Cultivated *Ulva intestinalis* at Kesknõmme experimental farm in September of 2019.

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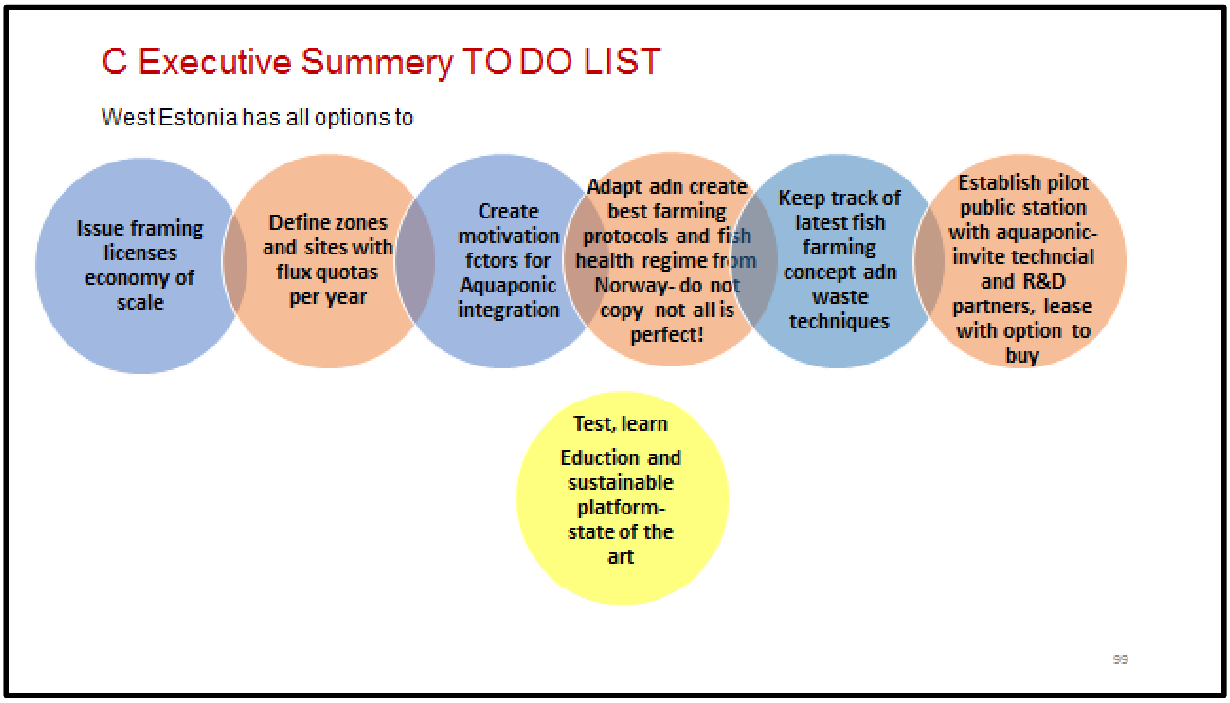
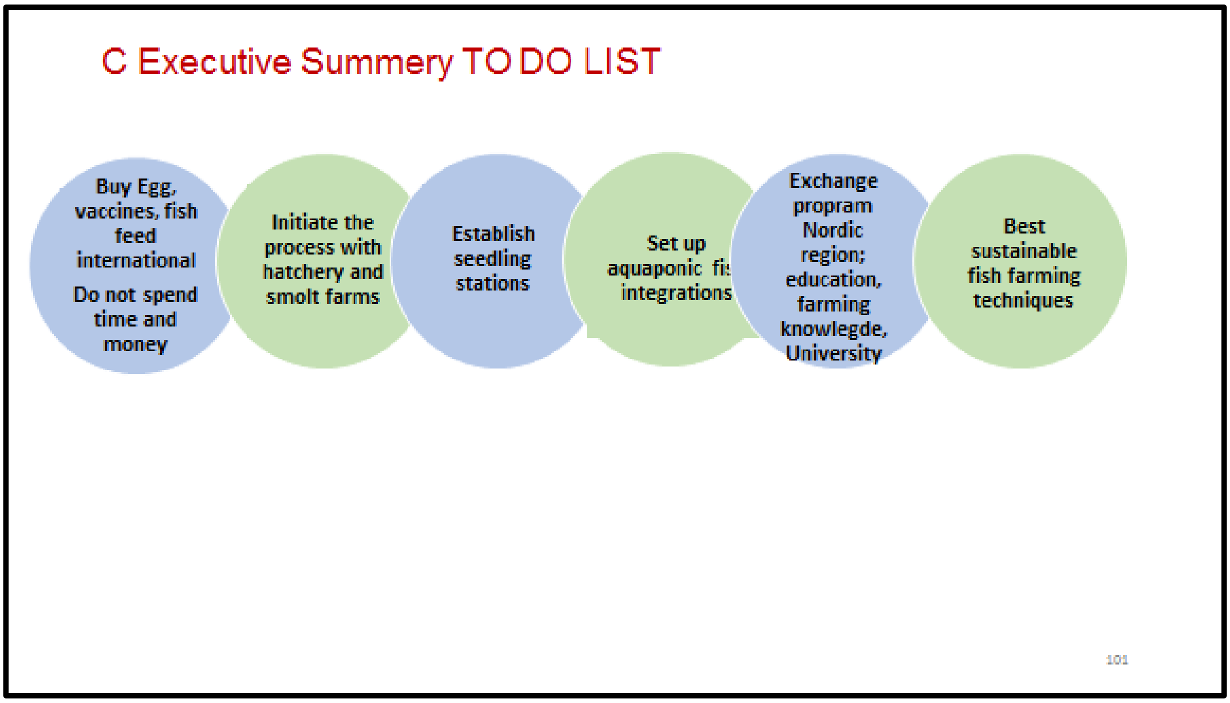
D TO DO list/ elements

Below is listed various TO DO actions. It is important that WEM do spend time and allocate resources for its strategic direction in evaluation the way forward. Our circular economy estimates are conservative; in Norway there is approx. 3x land jobs per every fish farming production staff, and there is approx. 300 tonnes productivity for each such staff. For our West Estonia estimates we have rather kept it as job:job as 1:1 and a productivity as 100 tonnes per man-year.

Inspection and visiting i.e. Norwegian fish platforms, and key fish health, licenses staff within the public aquaculture department is considered to be very valuable. A suggestion could be to meet such public staff first, then to visit the fish farms.

A video meeting with the leader of the Danish sea based Open net trout farmers will highlight valuable elements too.





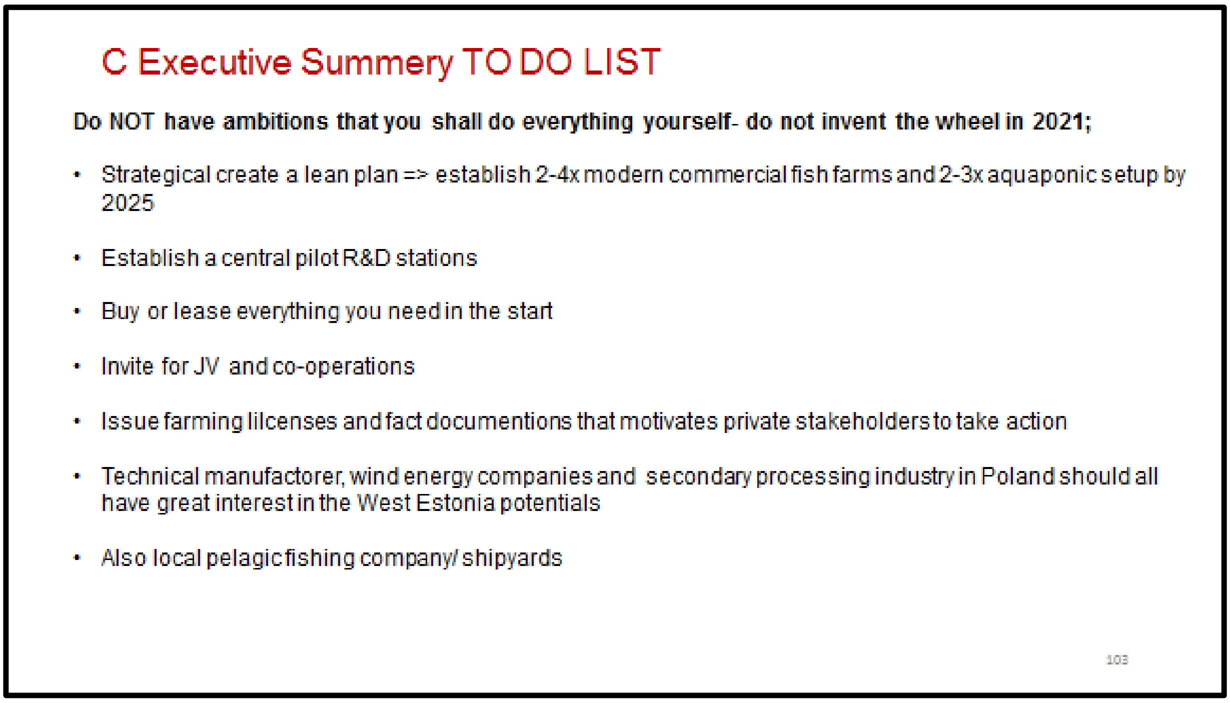


Figure 79 TO DO list.

<u>Comments;</u>

We consider that setting up a R&D station where science and practical farming and aquaponic activities can share resources and knowledge is very important. A separate document, meant for restricted distribution related how to set it up, it stakeholders, how to create contributions (opex, labor, capex) is part of this report.

Figure 80 TO DO list Pilot station.

Comments;

These floating units is owned and operated by the largest private R&D company in Norway, LetSea AS, www.letsea.no. They are by far the largest owner and operator of floating fish bags.

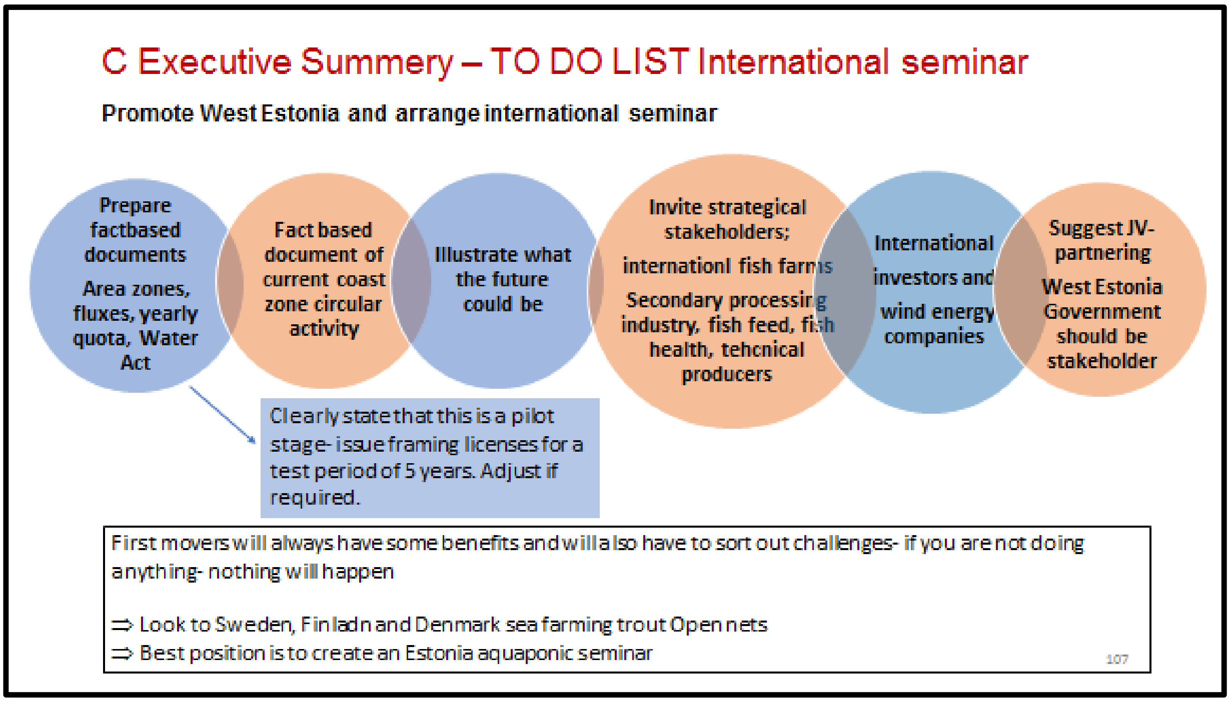


Figure 81 International seminar.

Comments;

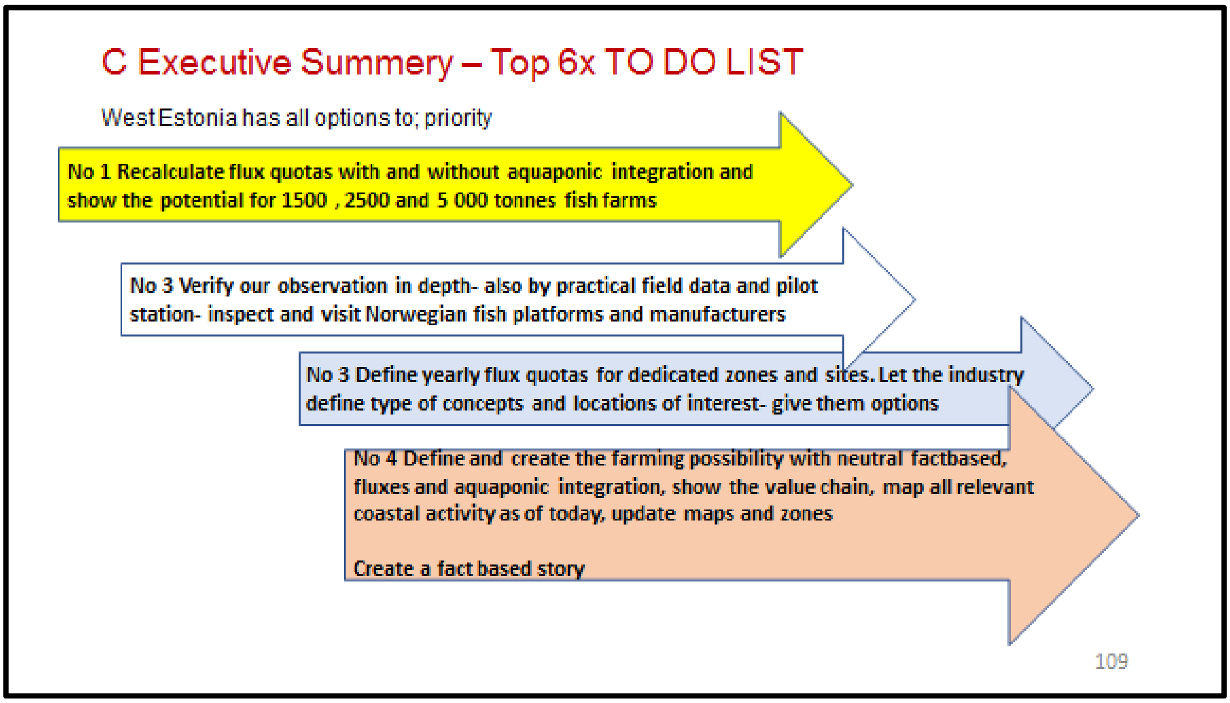
General fact based, English version, of the structure of the various elements to current circular coastal economy is very valuable- There potential stakeholders will see that there is a valuable structure today, that they do not have to invent everything from scratch. List of company, web pages, location and main activity will reduce the risk factors for an expansion phase. Private and public sector must be part of such overview.

Create drafted, illustrations of areas where the public sector do consider to be the best aquaculture zones. Licenses and biomass quota must not be 100% finalized, but ranges could be shown i.e. 500.1 00 tonnes, 1500-2000 tonnes or > 2 000 tonnes. All linked to flux quantity per kg fish produced.

<u>More precise Water Act definition;</u>

The definition of what is fish produced must also be shown, is it the live harvested swimming biomass or is it the harvested plus the round weight of the mortality? This will influence the total fluxes to sea.

<u>The most important 6x TO DO elements;</u>



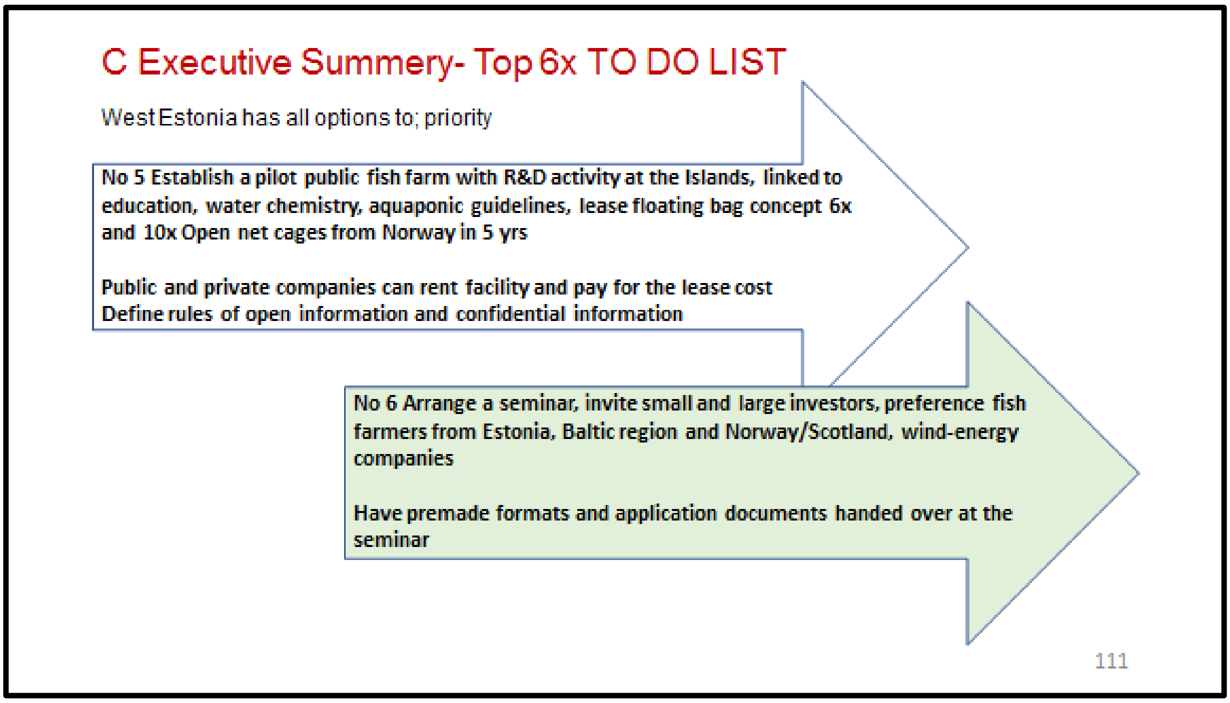


Figure 82 Various TO DO elements.

E Summery of circular economy observations

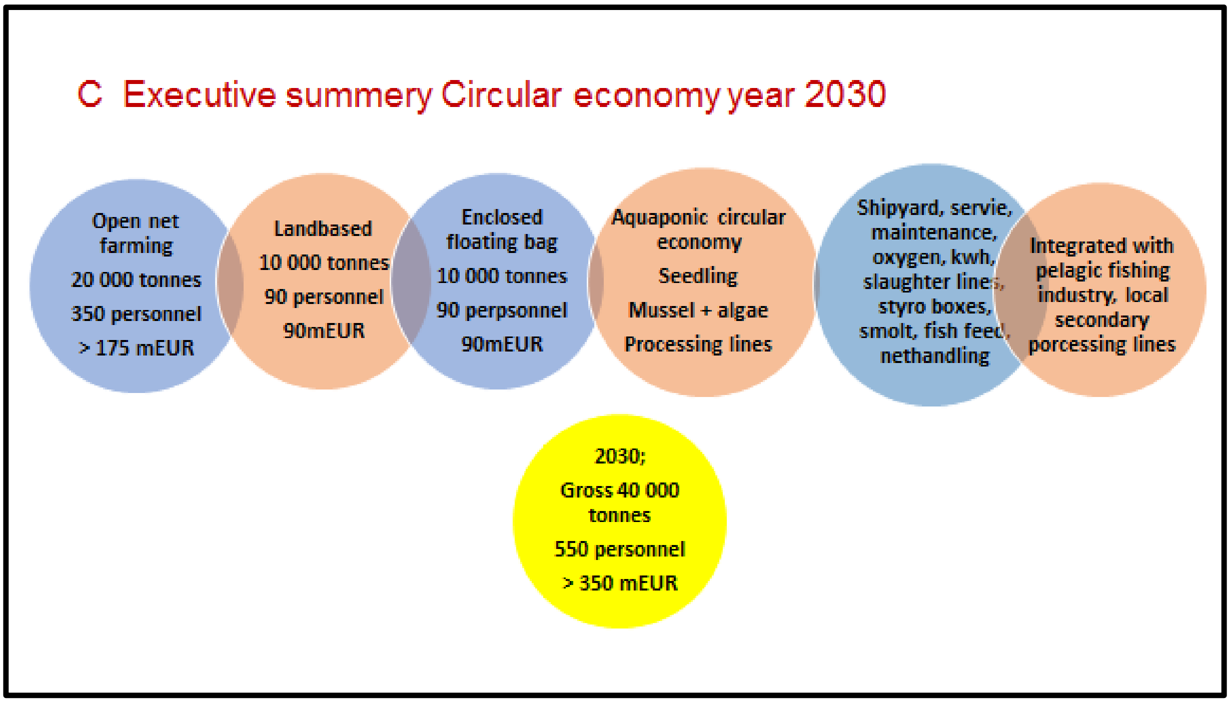


Figure 83 Gross circular observations.

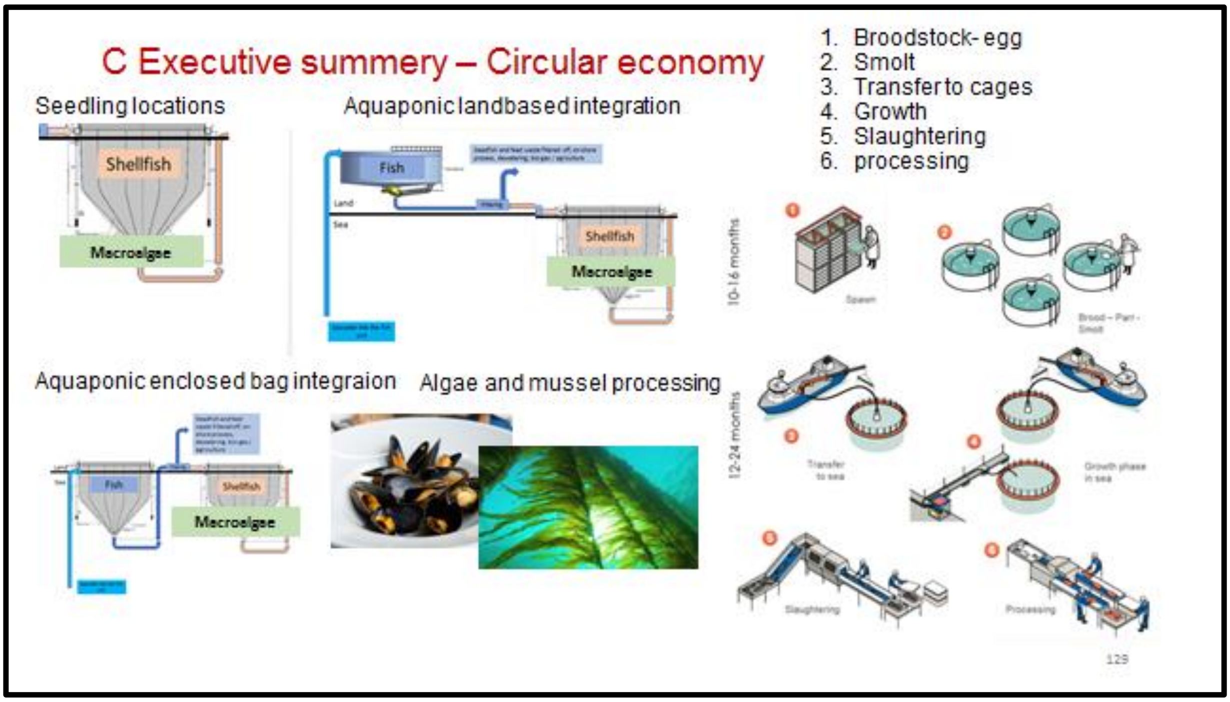


Figure 84 Illustration of the potential integration elements for an aquaponic setup West Estonia.

C Executive summery Fish biomass potential
sea area 100 km x 10 km => 1 000 km2
Open net platform;

With a distance of 125 km there should be room for; **20x sites each 5 km apart**

10x sites (small fish) and 10x sites (large fish) seperate generations

Generation harvest 10x a 2 000 MT => sum 20 000 MT/generation => 7 mill smolts
Identify, learn and adjust minimum 20 m depth- risk factor

On land fish tank platform;

First 1-2 large smolt plant locations, then 3x new

Then 4x ongrowing locations 4x a 2 500 MT/yearly => sum 10 000 MT/year
Identify, learn and adjust

Floating fish bag platform;

6x sites each 10x bags, each bag holding 200 MT at max generation harvest 6x10 bags => 1 200 MT x 10= 12 000 MT/ generation - Identify, learn and adjust

Figure 85 Some criteria and fish farming biomasses.

<u>Comments;</u>

If Open nets have dimensions as -10 m deep nets and a wish to have additional 10 m to the seabed- we are talking about location that have a gross depth of -20 m Such location with good current could be suitable, however the less depth under the cages normally the less natural distribution of the wastes. This may be negative in a longer perspective as organic wastes can be accumulated over time.

Other locations with larger depth will be even better, one could however rank and priorities such current and dispersal capability to the biomass per site or more accurate to a yearly flux quantity quota. Should it turn out that these initial quotas was too large, well then one could adjust accordingly. Opposite the other way round.

Moving further out from the coast West Estonia should be well suited to with larger farming licenses, the sizes should be evaluated according to the waste and environmental impact. We stress here that our suggested aquaponic units for enclosed lop of wastes is currently not dimensions for the weather and ocean forces in the outer coastline. Significant wave heights to some of the manufacturer today is said to be in the range of 2.5 m. There are however enclosed setup where larger oil tankers and Suezmax ships can be modified with enclosed bag arrangements. We are aware that such ideas do exists, and one example is the current Chinese plans for exploiting Atlantic salmon in the Southern ocean between China and Taiwan with a fleet of ships with protect fish holding units. In this region there are regular typhoons that otherwise is considered to be a major risk factor.

A second hand maxi ship could be considered for the more exposed West Estonia zone, or some of the concrete enclosed fish farms also being developed in Norway and UK for time being could also be considered. These new concrete version is not being made yet. We strongly therefor suggest that West Estonia address such potentials also to candidate within the wind-energy sector, se figure xx below.

F Public report Baltic Sea, activities, conditions and environment

The characterization of the West Estonian region from an aquaculture perspective has been detailed described 2020:

”AQUACULTURE IN ESTONIAN MARINE WATERS, UNDERLYING DATA AND RESEARCH” JONNE KOTTA, GEORG MARTIN, REDIK ESCHBAUM, ROBERT APS, LIISI LEES, RISTO KALDA - ESTONIAN MARINE INSTITUTE OF THE UNIVERSITY OF TARTU

Below is copied some of the information from the listed Report above, however by goggle translate that may be of interest;

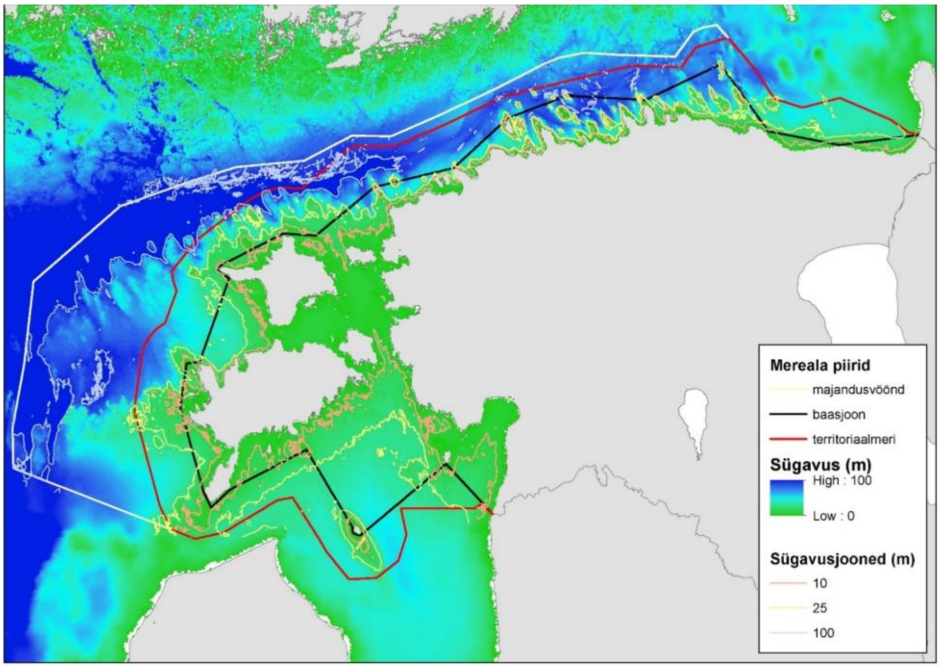
Political guidelines promoting the growth of aquaculture are outlined in the European Union's sustainable development of aquaculture strategy of 2002. This strategy improved the environmental impact, safety and quality of aquaculture products in the European Union (Communication from the Commission – Progress Report on the Sustainable Development Strategy, SEC(2002) 511). Estonia has good prerequisites (including fish, water and land resources) for the production of fishing and aquaculture products. Companies in the fishing sector have long-lasting traditions, expertise and experience in addition to implementing modern technological solutions and technologies for production and environmentally friendly pisciculture. The Estonian aquaculture sector is currently comprised almost entirely of pisciculture; alternative trends that restore natural environments are lacking. New, environmentally friendly aquaculture fields such as farming mussels and seaweed are being introduced (Ministry of Rural Affairs 2020).

While piscicultures established in natural bodies of water increase nutrient strain on the environment, mussel and seaweed farming are seen as a flagship of environmentally friendly economics in the European Union as they remove nutrients from the sea environment (Kotta et al. 2020).

In 2018, Estonian aquaculture companies sold 944 tonnes of fish and crawfish worth 4.2 million euros. The volume of aquaculture produce sold in 2018 was the highest of the past 25 years (Statistics Estonia 2019). Estonia has good prerequisites for producing aquaculture products according to the ‘Agriculture and Fisheries Development Plan to 2030’ (Ministry of Rural Affairs 2020). The potential production capacity of Estonian aquaculture companies has been estimated to be more than 4000 tonnes per year. There has been a rise in demand for fishery products in the European Union, and aquaculture is seen as a potential solution to the rising demand for animal protein, taking into account that fishing and aquaculture are one of the most effective ways of producing it. Marine waters potentially suitable for aquaculture and the need to develop infrastructure are described in a study conducted by the Estonian University of Life Sciences (2015). However, the underlying conditions for aquaculture have changed a lot in the past five years (such as laws and the ongoing spatial planning of Estonian maritime areas) and new knowledge about cultivating aquaculture species has been gained. Creating a new overview is essential for interest groups to be able to orientate themselves in the aquaculture field.

The size of the Estonian marine area is approximately 36,500 km2 (i.e. almost 10% of the Baltic Sea), of which the Exclusive Economic Zone takes up one-third, with an area of 11,300 km 2. The length of the Estonian coastline (based on the base map, and including islands and islets) is *ca* 4015 km.

The marine area under Estonian jurisdiction lies in the north-east of the Baltic Sea and is comprised of several large Baltic Sea basins that differ from one another greatly due to natural conditions and human activity. These basins are the Gulf of Finland; the open part of the Western Isles; and the Gulf of Riga, which includes the Väinameri strait located in the area of the western-Estonian archipelago. Coastal waters are divided into 16 coastal water bodies according to the Water Act. These bodies are divided into six types of coastal waters based on their natural properties (Regulation no. 44 of the Minister of the Environment) (Ministry of Environment 2019).



Maritime borders

The maritime boarder of Estonia.

Water **temperature and salinity** are important factors in determining the borders of distribution for species characteristic −of the ecosystem, including the distribution potential for aquaculture species and the relative abundance of species in their habitats. The salinity of the Estonian marine area varies greatly between areas. In the open Baltic Sea, salinity can be as high as 10 g/kg, while smaller bays have relatively fresh water. The salinity of a certain area does not vary much temporally in general, with the variation being no more than a few salinity units. Water temperature is usually highest in Estonia's coastal waters at the end of June and in August.

The Baltic Sea is characterised by a phenomenon that is extremely important for aquaculture. Namely, the Baltic Sea proper is stratified and is marked by both seasonal stratification (temperature-based) and constant stratification (based on the density of seawater, i.e. its salinity). Seasonal stratification occurs in summer when the uppermost layer of water warms up, creating a 10−20 m thick warm layer. This layer can warm up to 20−25 degrees Celsius. The water beneath this layer remains close to 4−5 degrees Celsius. This kind of stratification lasts for a few months until it is eradicated by autumn storms. Stratification caused by the salinity of water masses is constant. This is expressed through the change in the level of a number of physical-chemical parameters at a depth of around 50−60 m. At this depth, water salinity (and thus density) rises sharply. The drop in **oxygen concentration** caused by this change is of aquacultural and ecological importance. Oxygen concentration in the layer nearest to the seabed is the most decisive indicator of the 'health' of the Baltic Sea.

Eutrophication is one of the biggest environmental problems faced by the Baltic Sea. It is caused by the accumulation of nutrients (mostly compounds of nitrogen and phosphorus) in the marine environment. Both simple and complex phenomena can be caused by eutrophication, either within singular components of an ecosystem or ecosystem-wide. Some can be positive for human society (such as large secondary production, i.e. plankton-eating fish like Baltic herring and sprats developing large biomass), but others can be negative (growth in primary production – algal blooms, lack of oxygen in the bottom layers of the sea and lessening of species variety).

2. Pisciculture and fishing

A large part of Estonian **pisciculture** produce comes from freshwater pisciculture. One company is currently farming fish in sea cages. Suitable water resources are necessary to develop freshwater pisciculture. An appropriate location is necessary for surface water pisciculture, as the freshwater body must be self-flowing, either through water pumps or damming. Thorough preparatory work is necessary to find the right location.

Estonia's only cage fishery is located in Tagalaht near Veere. Cage fisheries were somewhat active near Veere in Tagalaht near Veere and in the Kolga Bay in Salmistu in the 2000s. They were closed in the second half of the 2000s. The reasons behind these closures vary. Many of the fisheries were established with the help of the European Maritime and Fisheries Fund but failed to meet the standards set by the project (planning faults in buildings, incorrect financial plans, etc.).

The fish best suited to Estonian pisciculture is the rainbow trout. When establishing a fishery, it is important to make sure that the marine area is deep enough and that the appropriate currents provide the fishery with fresh water. The fish can be farmed during ice-free periods, since ice and volatile weather can destroy the cages. Estonia lacks deep marine areas protected from the wind (such as Finland's Åland Islands). This must also be considered when choosing a location for the cages.

Fishing takes place throughout Estonia's marine area, except in areas where it is forbidden by law. Coastal and recreational fishing is intense in coastal areas and areas with a lower sea level. It is recommended to utilise industrial fish stock in a manner that allows for a yield of similar size the following year. Industrial trawl fishing (Baltic herring and sprat) takes place in marine areas deeper than 20 m. Trawling is forbidden in shallower waters, as it damages the seabed and therefore affects biodiversity.

4. Farming large seaweed

Large seaweed species are those with measurements larger than 2 cm. The Baltic Sea is home to over 550 species of large seaweed. The spread of such seaweed in the Baltic Sea is affected by salinity, the existence of a suitable substrate, openness and water transparency. Each species requires a certain set of ecological factors in order to thrive. The seabed in Estonia's coastal sea is not diverse in plant species due to low salinity. Up to 80 species of seaweed and taller plants can be found in our waters. Around 20 of those species occur commonly. Some aquaculture technologies can help control and modify environmental factors (such as substrate, the impact of waves, the concentration of nutrients and the availability of light), but not all environmental parameters (e.g. salinity) can be controlled in this manner. As such, it makes sense, in the context of aquaculture, to farm species already native to the Baltic Sea.

Large seaweed is the most suitable for aquaculture as it grows very quickly, uses up the most nutrients and can compete with other species for resources. As part of the 'Compiling of regional aquaculture designs to control potential environmental pressure' project (University of Tartu 2019b), a list of the large seaweed species native to the Estonian coastal sea, their economic potential and their ability to offset environmental risks was compiled. The species of large seaweed with aquaculture potential are *Fucus vesiculosus*, *Furcellaria lumbricalis*, *Cladophora glomerata* and *Ulva intestinalis*. The correlation between environmental factors and the production of large seaweed was modelled based on these species, and their potential growth rates in the Estonian marine area were estimated. In parts of the Baltic Sea with lower salinity, including Estonia, seaweed culture has not yet become an economic activity and the few experimental farms which have been constructed are still only in the development phase. It is necessary to establish a few pilot seaweed and mussel farms in the Estonian marine area to assess their economic effectiveness and their efficiency in removing nutrients from the marine environment (assessing the number of nutrients extracted from the sea and the scope of the effect). It is also necessary to assess any negative effects such farms could have on the environment. Smaller, more widely distributed farms a couple of hectares in size are preferable. Smaller farms produce higher yields per unit of area, they can remove a larger amount of nutrients from the marine environment at the same investment rates as large farms and their potential negative impact on the environment is smaller (University of Tartu 2019b).

The following is a description of the species of large seaweed best suited to aquaculture in the Baltic Sea. **Furcellaria** is native to the entire North-Atlantic area and is a very common species in Estonian waters. It appears in two forms: the most common is attached Furcellaria, which inhabits moderately or completely open coasts at depths of 5−10 m on hard substrate; while the second form is loose-lying Furcellaria, which can only be found on seabed that are hydrologically compatible (usually on soft bottoms in archipelagos). In Estonia it is found most commonly in the Väinameri Strait and it is industrially harvested in Kassari Bay. Furcellaria's natural spread is well documented and thus is able to be modelled. Furcellaria is a very sturdy species and is able to withstand lower salinity (up to 3−4 g/kg).

Its life cycle is complex and includes several stages (Figures 4.1 and 4.2). Both sexual and asexual reproduction have been noted in the Furcellaria found in the more saline southern part of the Baltic Sea. In the northern part of the Baltic Sea, only two methods of asexual reproduction have been described: reproduction via tetraspores and fragmentation. Fragments of the seaweed thallus have the ability to reattach themselves to substrates. However, these reproductive processes are in need of further research. A number of studies have been conducted in Estonia in which duplication of both the tetraspores and fragmentation reproduction methods have been attempted. These efforts have not yet borne fruit as the seaweed has not attached itself to an artificial substrate.

Furcellaria is the only **industrially used large seaweed** species in Estonia. Gelling polysaccharides are manufactured from it. It is collected from beaches and trawled from the sea in the Väinameri Strait. The first instance of this kind of collection can be traced back to the late 1960s. According to statistics, 653.9 tonnes of seaweed was gathered from the Väinameri Strait in two years (2014−2015) (University of Tartu 2019a).

Fucus vesiculosus is one of the most widespread species in the Baltic Sea. It is found throughout the parts of the sea where salinity is higher than 3−4 g/kg and where suitable substrates can be found in the euphotic zone. Fucus vesiculosus can be found in deeper marine areas than Furcellaria. Fucus vesiculosus has been known to grow in areas of the Baltic Sea with varying hydrodynamic conditions or water properties.

Its reproduction cycle is well documented, but complex. Fucus vesiculosus mainly reproduces sexually (Figure 4.3). Artificial reproduction has only worked in very rare cases (Fordlund & Kautsky 2013). Vegetative reproduction in fucus vesiculosus has been described in rare cases, mostly occurring under experimental circumstances (Schagerström 2013). The seaweed also possesses very good regenerative ability (e.g. after ice damage).

Ulva intestinalis is an aquaculture species with among the greatest potential due to its rapid increase in growth. The species occupies a large part of the Baltic Sea and can also be found in fresh water. It has a simple reproduction cycle (Figure 4.4). Farms growing freshwater *Ulva* are being established in Germany, the Netherlands and various Asian countries. This species is better cultivated in containers rather than open water, due to its delicate structure. Technological solutions in Estonia for cultivating *Ulva* in containers are still in the testing phase. When growing, the plant does not need to be attached to a substrate but can float freely in a water gauge. This property makes its cultivation a lot simpler.

The 'Treatment of marine water-based pisciculture waters via the cultivation of macroalgae' project is currently being conducted by the Estonian Marine Institute of the University of Tartu (end date: March 2021). Although this project is not aimed at the cultivation of *Ulva*, the weed is still used as a test species for removing nutrients from waste water originating from fisheries. Experiments conducted as part of the project have achieved good results and *Ulva* will likely be the species to help effectively clean fisheries' waste water. More information regarding the project can be found in Chapter 8.

Macroalgae production/ harvest in West Estonia region

Currently, the only species of large seaweed industrially farmed in Estonia is *Furcellaria lumbricalis*. It is either collected from the shore or trawled from the seabed. Est-Agar AS is the only user of *Furcellaria lumbricalis* seaweed in Estonia. The amount of seaweed collected and processed annually is around 1000 tonnes (wet weight). The yearly production of furcellaran has been on average 50-60 tonnes in the recent years (Fisheries Information Centre & SakiConsult OÜ, 2018). Experiments with collecting and processing other species have been undertaken (e.g. collecting *Fucus vesiculosus* to use it in cosmetics and as food).

Based on the experience of neighbouring countries, big vessels are not used when maintaining seaweed and mussel farms and collecting produce. Sweden uses vessels with draughts of no more than 1.5 m to collect produce. Mussels are collected in 2 m3 bags, and only a small crane is needed to unload them at the port. As such, seaweed and mussel farms do not require specialised solutions at ports and most smaller ports can be used to service the farms.

Summery and status of the Water Act for aquaculture business

The Water Act (VeeS) is the most important act for potential aquaculture businesses to follow. A new Water Act came into effect in October 2019. The previous Water Act dated from 1994. An important change to the act is that a permit is no longer needed for activities that pose no danger to the water environment. Activities with limited impact need to be registered with the Environmental Board, but this process is much simpler than applying for a permit for the special use of water. The definition of a body of water is also specified – sewage treatment plant lagoons, aquaculture lagoons and basins are no longer treated as bodies of water.

On the basis of §131 section 2 of VeeS, the regulation **'Water protection requirements for aquaculture and limit values for pollutant concentration of effluent water from aquaculture and requirements for discharge of such water into a recipient and monitoring thereof' was established in April 2020.**

The new Water Act treats water discharged from aquaculture as different from sewage. As such, a new empowering provision was established for the regulation. This regulation provides changes in determining the number of pollutants and assessing pollution costs in the event that the limit of pollutants allowed in the special use of water is exceeded. Previously, the number of pollutants in the water discharged by fish farms was determined through an analysis conducted using water samples. Pollution costs were calculated based on the difference between the indicators of incoming and outgoing water of the fish farm and the Environmental Fee Act. The explanatory statement to the new regulation outlines that a conceptual change has taken place: to determine the pollution levels spreading into nature from aquaculture companies, **a nutrient-based calculation method will be used.**

This approach will help to more effectively assess the amount of pollutants making their way from the farm into the environment and thus assess the impact the farm has on the environment. This will improve the inspection of pollution sources and reduce the impact pollutants have on the environment. This in turn will have an economic impact on owners of fisheries, as the method for assessing the pollutant amounts necessary for calculating pollution costs will be changed. The goal of this change is to encourage owners to use effective feed whose effect on the environment (i.e. the amount of pollutants in the water exiting the fishery) is minimal effect on the environment (i.e. the amount of pollutants in the water exiting the fishery) is minimal. This will also be beneficial to the owners as they will be allowed to produce more while adhering to the same amount of pollutant load (Ministry of the Environment 2020).

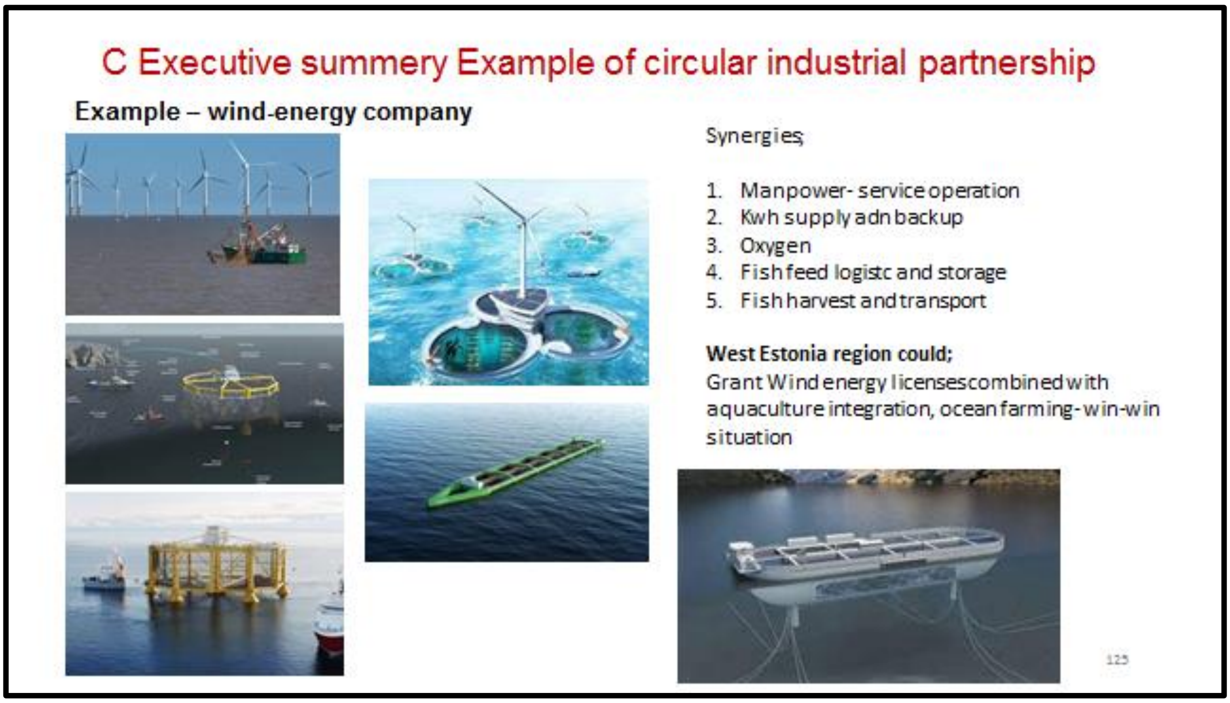
Sea aquaculture and aquaculture in public bodies of water

The following chapter provides an overview of permits and establishments instrumental to launching marine aquaculture in public bodies of water, including cage fisheries in the coastal sea. Public bodies of water are listed in § 23 of VeeS. The chapter will also advise on the first steps towards procuring all necessary permits, but the overview does not contain every detail.

G Wind energy sector

We consider that a strategic well considered plan to integrate wind energy licenses with fish farming activity is

- Combining two natural resources that actually share many similar tasks and conditions
- Need very much of the same "type" of service, maintenance, inspections
- A careful planning of wind platform linked to fish and aquaponic platform is representing a huge potential- win-win
- Aquaculture setups need kwh, oxygen and backup system
- Feed storage, pumping and harvest services, also wellboat for smolt and shipping market sized fish to processing plant
- A eco-friendly sustainable profile, marketing and goodwill creating is considered to represent huge potential of all stakeholders involved
- Criteria for issuing wind energy licenses should be considered where such partners also had to offer time, resources for such integration potentials



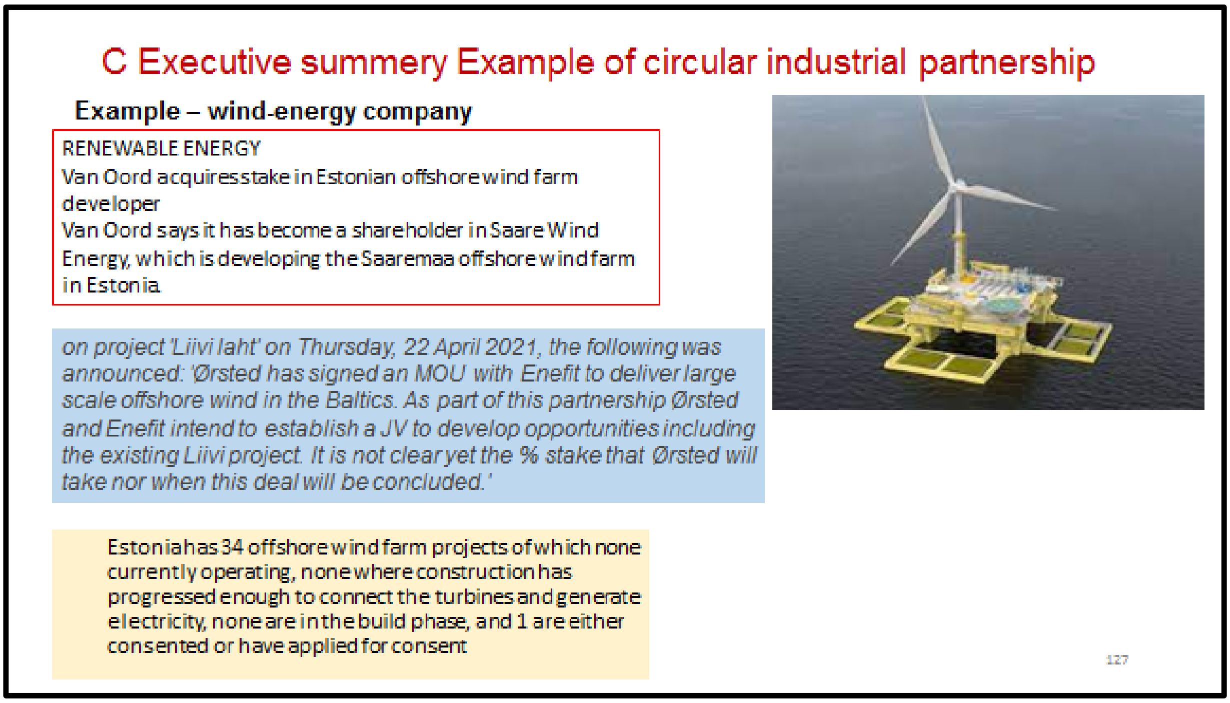


Figure 86 Some Wind-energy illustrations.

H International fish framing information

Below is various elements that have important information elements.

We strongly advice stakeholders to read the Industry Report a yearly public report made by the largest salmon farming company Mowi ASA (www.mowi.com). This is among the best objective summery of major elements linked to marine protein, farming conditions, biomasses and future challenges.

https://mowi.com/blog/annual-report-2020/

Illustration of food conversion ratio protein

Stagnant wild fishing catches and growing aquaculture, source; Moowi AS Industry handbook 2020

2.4 Stagnating wild catch – growing aquaculture

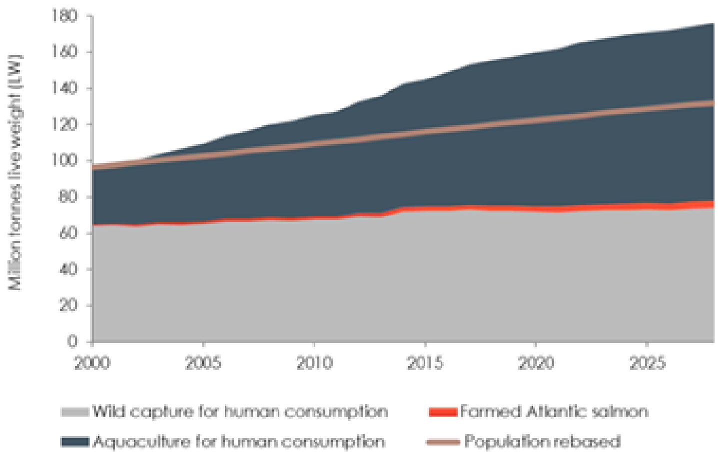


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Illustration of food conversion ratio protein

Carp, mollusks and crustacean's dominant the sea food volume, a large proportion of total sea food volumes is cultivated. Source Mowi ASA Industrv handbook 2020

Positioning of Salmon

2.6 Salmonids contribute 4.4% of global seafood supply

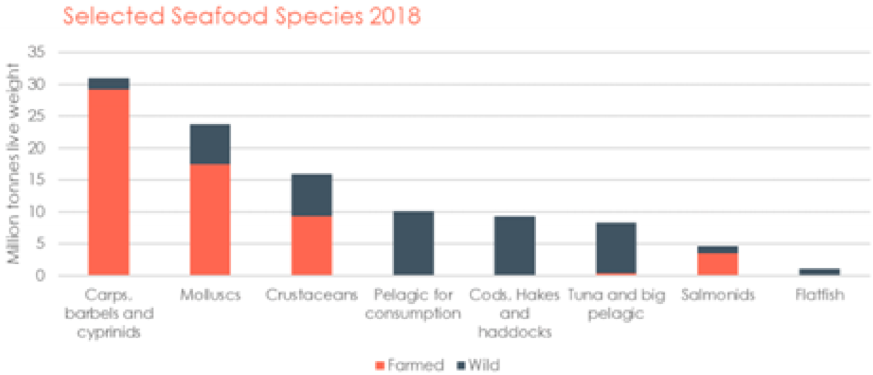

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Illustration of food conversion ratio protein

Farmed Atlantic salmon and large trout. Source Mowi ASA Industry handbook 2020

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Illustration of food conversion ratio protein

Coastlines for Atlantic salmon production; Source Mowi ASA Industry handbook 2020

4.3 Few coastlines suitable for salmon farming

The main coastal areas adopted for salmon farming are depicted on the above map. The coastlines are within certain latitude bands in the Northern and Southern Hemispheres.

Activate Wind

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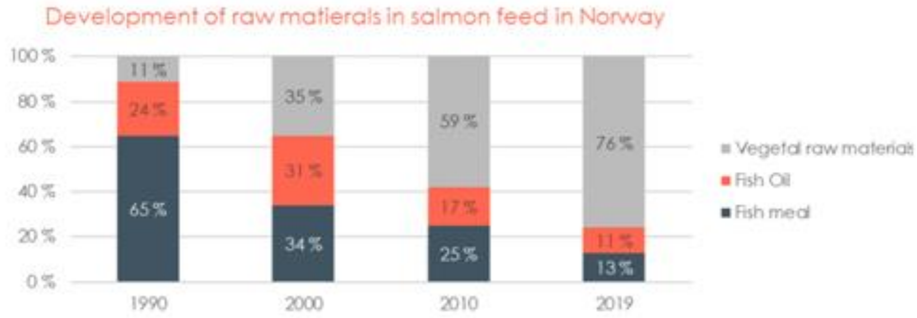
Illustration of food conversion ratio protein

Salmon fish feed; Source Mowi ASA Industry handbook 2020



* Life Cycle Assessment (LCA) determines the environmental impacts of products, processes or services, through production, usage, and disposal
Source: SINTEF (2020) Greenhouse gas emissions of Norwegian seafood products in 2017, Ytrestøyl T., Aas T.S., Åsgård T. (2014) Resource utilisation of Norwegian salmon farming in 2012 and 2013, NOFIMA, Mowi

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Potential industrial partners West Estonia

7.1 Top 5-10 players of farmed Atlantic salmon 2019

	Top 10 - Norway Company	H.Q. HOG	Top 5 - United Kingdom Company	H.Q. HOG	Top 4 - North America Company	H.Q. HOG	Top 10 - Chile Company	H.Q. HOG
1	Mowi	236,900	Mowi	65,400	Cooke Aquaculture	56,500	"New Aquachile" (Agrosuper)	141,300
2	Salmar	153,100	Bakkafrost (SSC)	33,800	Mowi	54,400	Salmones Multiexport	77,600
3	Lerøy Seafood	128,700	Scottish Sea Farms	25,900	Mitsubishi / Cermaq	17,800	Mitsubishi / Cermaq	71,900
4	Mitsubishi / Cermaq	73,000	Cooke Aquaculture	23,400	Grieg Seafood	14,100	Mowi	65,700
5	Grieg Seafood	57,600	Grieg Seafood	11,300	*		Australis Seafood	53,500
6	Nova Sea	46,000	*				Camanchaca	48,300
7	Nordlaks	35,000					Salmones Antartica	27,100
8	Sinkaberg-Hansen	30,500					Salmones Blumar	25,700
9	Alsaker Fjordbruk	30,500					Salmones Austral	22,800
10	Norway Royal Salmon	30,500					Yadran	22,500
	Top 10	821,800	Top 5	159,800	Top 4	142,800	Top 10	556,400
	Others	378,300	Others	5,400	Others	5,100	Others	64,800
	Total	1,200,100	Total	165,200	Total	147,900	Total	621,200

All figures in tonnes GWT
* The industry in the UK and North America are best described by the top 5 and top 4 producers, respectively.

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Investment situation Norway vs West Estonia – Fish farming

A 4 200 MT gutted salmon production costs;

License MEUR 60
Capex MEUR 5

Inventory cost of biomass, 4,2 mill kg gutted x EUR 5,00/kg = 21 MEUR

Total invested first generation; MEUR 87

West Estonia total investment MEUR 26

Cost avoidance MEUR 60, over 20 yrs=> MEUR 3/yr

10.2 Capital return analysis

Investments and payback time (Norway) - assumptions

- Normal site consisting of 4 licenses

- Equipment investment: MEUR 3.5 - 4.5
- Number of licenses: 4
- License cost (second hand market) MEUR: 60 (~MEUR 15 per license)
- Output per generation: ~4,200 tonnes GWT
- Number of smolt released: 1,100,000

- Smolt cost per unit: EUR 1.7
- Feed price per kg: EUR 1.3 (LW)
- Economic feed conversion ratio (FCR): 1.2 (to Live Weight)
- Conversion rate from Live Weight to GWT: 0.84
- Harvest and processing incl. well boat cost per kg (GWT): EUR 0.4

- Average harvest weight (GWT): 4.5kg
- Mortality in sea: 15%

- Sales price: EUR 5.9/kg

Source: Mowi Industry handbook 2020

Farming license regime

Due to biological constraints, seawater temperature requirements and other natural constraints, farmed salmon is only produced in Norway, Chile, Scotland, the Faroe Islands, Ireland, Iceland, Canada, USA, Tasmania and New Zealand.

Atlantic salmon farming began on an experimental level in the 1960s and evolved into an industry in Norway in the 1980s and in Chile in the 1990s.

In all salmon-producing regions, the relevant authorities have a licensing regime in place. In order to operate a salmon farm, a licence is the key prerequisite. Such licences restrict the maximum production for each company and the industry as a whole. The licence regime varies across jurisdictions.

Source: Mowi Industry handbook 2020

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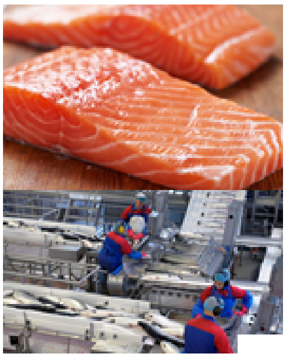
Secondary processing fish farming – Poland/Denmark 250 000 MT- 55 trucks or 55 000 boxes(18kg) per day

Source: Mowi Industry handbook 2020

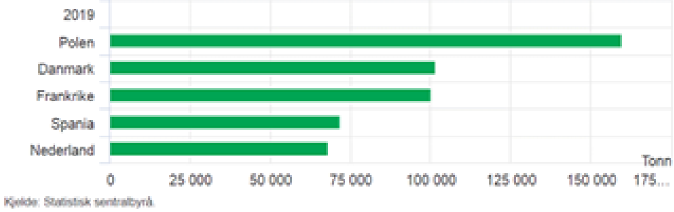


In processing we distinguish between primary and secondary processing.

Primary processing is slaughtering and gutting. This is the point in the value chain at which standard price indexes for farmed salmon are set.

Secondary processing is filleting, fillet trimming, portioning, producing different fresh cuts, smoking, marinating or breading. Depending on the setup of the processing plant, products are fresh packed with Modified Atmosphere (MAP), vacuum packed or frozen and stored for distribution.

Products that have been secondary processed are called value-added products (VAP), as they represent an additional value to the retailer and foodservice operator but most of all to the final consumer.



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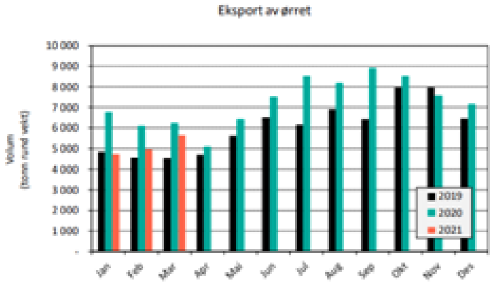
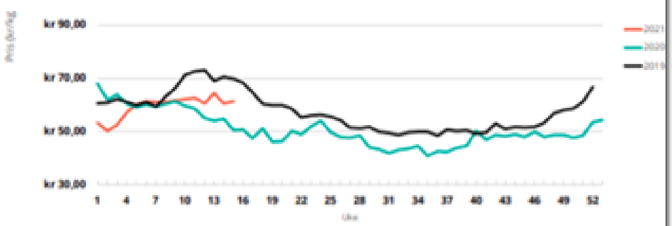
Farmed volume and price fresh rainbow trout Norway 2019-21

Norway export rainbow trout volume - 85 000 MT/yr

Norway export price fresh gutted in box NOK/kg





Source: Akvafakta.no

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