



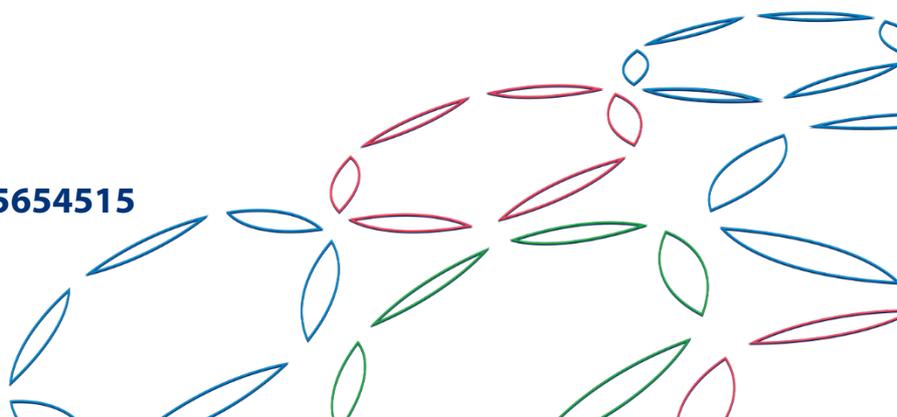
# **SustainCycle – Vertical farming of abalone** **/ SustainCycle - Lóðrétt Stórskalaeldi á Sæeyrum**

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## Report summary

<i>Titill / Title</i>	SustainCycle - Lóðrétt Stórskalaeldi á Sæeyrum/ SustainCycle – Vertical farming of abalone		
<i>Höfundar / Authors</i>	Sophie Jensen		
<i>Skýrsla / Report no.</i>	21-21	<i>Útgáfudagur / Date:</i>	Nóvember 2021
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<i>Ágríp á íslensku:</i>	<p>Markmið verkefnisins var að byggja grunn til að skala upp sæeyrnaeldi á Íslandi. Heimsmarkaðurinn hefur vaxið með undraverðum hætti undanfarin 10-15 ár og allt bendir til að vöxtur verði áfram. Sæbýli hefur nú byggt upp aðstöðu í Eyrabakka fyrir áframeldi og Þorlákshöfn fyrir undaneldi og frjóvganir. Við upphaf verkefnisins var framleiðsla inn á markað á fyrstu stigum en eldisstöðin hefur framleiðslugetu upp á 70 tonn/ári inn á heimsmarkað sem telur amk 150 þúsund tonn. Langtímamarkmið Sæbýlis er að byggja upp sjálfbæran eldisiðnað á Íslandi með því að byggja upp staðlaðar framleiðslu einingar víðar á Íslandi. Til þess að svo verði þurfti að leysa ákveðnar tæknilegar hindrandir fyrir uppskölun og út frá því hanna „state-of-the-art“ staðlað framleiðsluhús. Ennfremur var markmiðið að kanna hollustu og heilnæmi afurðanna ásamt því að meta umhverfisáhrif framleiðslunar. Að lokum var áætlað koma á samskiptum við íslenska neytendur, veitingastaði og hagsmunaaðila ásamt markaðsaðgerðum erlendis.</p> <p>Að verkefninu stóðu Sæbýli, Matís, Háskóli Íslands og Centra.</p>		
<i>Lykilorð á íslensku:</i>	<i>Sæeyra, fiskeldi, uppskölun, umhverfisáhrif, heilnæmi</i>		
<i>Summary in English:</i>	<p>The aim of the project was to build a foundation to expand abalone production in Iceland. The international market has grown incredibly during the last 10-15 years and will continue to grow. Currently, Sæbýli has built an aquafarm in Eyrarbakki and Þorlákshöfn and grow small scale abalone animals to market size. At the beginning of the project the farm had a capacity to produce 70 tonnes/year into a global market of 150 000 tons in total. The long-term plan of Sæbýli is to build a sustainable aquaculture industry in Iceland by building standardised production units in other parts of Iceland. In order for this to happen, certain technical barriers to upscaling had to be resolved and a "state-of-the-art" standard production facility had to be designed.</p> <p>Furthermore, the aim was to examine the wholesomeness of the product as well as to assess the environmental impact of the production. Finally, it was intended to establish communication with Icelandic consumers, restaurants and stakeholders, as well as marketing measures abroad.</p> <p>The project was carried out by Sæbýli, Matís, the University of Iceland and Centra.</p>		
<i>English keywords:</i>	<i>Abalone, aquaculture, scale-up, environmental impact, wholesomeness</i>		

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## 1. Introduction

Abalone is one of the most expensive of any seafood worldwide. The market has grown by 500% for the last ten years without apparent effect on prices. In 2002 farmed abalone global market was little less than 9000 tonnes and it is expected that in 2017 it will reach up to 150 000 tonnes with average prices around 55 USD/kg but goes up to 80 USD/kg. China is by far the largest producer and South Korea has been increasing its production during the last couple of years. Import/export global market is close to 10 thousand tonnes with potential value of 40 billion ISK with highest prices in Japan, Europe and USA.

Currently, the Icelandic abalone production is in its infancy with regards to export value. However, developmental production has been operated in Iceland for some years within the company Sæbýli. During this time a novel production system utilising recycling of seawater, custom designed biofilters and vertical farming has been developed under the SustainCycle™ concept. Today, the experience and know-how gained through these years opens the possibility of scaling up the production for export in a very cost effective and competitive way.

In two to three years' time, it is expected that Eyrarbakki reaches full production capacity of 70 tonnes according to the company's breeding plan. By then, Sæbýli aims to scale up by building new state-of-the art production facilities. The long-term plan of Sæbýli is to enlarge their market share up to over 1000 tonnes (valued over 5.5 billion ISK) by designing and building 5 abalone aquafarm facilities around Iceland with a central monitoring system.

The aim of the SustainCycle project was to build a foundation to expand abalone production in Iceland with the main objective to lay the groundwork for scaling up and overcoming challenges in the way. This included building onto the vertical farming SustainCycle™ and design a blueprint of a production facility which can be replicated in different locations around the country and address foreseen challenges in the expansion. Challenges were in developing smart solutions to reduce labour in monitoring and cleaning, improve logistics and management, and increase production per volume seawater.

The objective was further to acquire data to demonstrate to stakeholders that the SustainCycle™ system has near to zero environmental impact and delivers healthy and pure product.

## 2. Material and methods

### 2.1. Smart solutions development

#### 2.1.1. Utilisation model for rearing tanks

A model to maximise the utility of rearing tanks is vital for upscale planning. This research aimed to create a pre-architectural design for a new grow-out rearing facility of abalone for Sæbýli ehf. with the goal of reducing operational costs.

The work was performed by Sindri Snær Rúnarsson (University of Iceland) through his MSc essay " Forhönnun á áframeldisstöð fyrir Sæbýli ehf." The supervisor was Rúnar Unnþórsson. The MSc project was carried out in close collaboration with Ásgeir Guðnason at Sæbýli and Sigurður Harðarson at Centra. The MSc essay will be accessible in [www.skemman.is](http://www.skemman.is) in 2031.

#### 2.1.2. Automatic scalable surveillance system

Two student projects were engaged in investigating smart solutions for automatic monitoring. Automatic sensors and data transmitters were investigated to set up a central monitoring system, able to remotely monitor the environment, water quality and animal growth.

### 2.2. Environmental discharge data

To demonstrate low to zero environmental impact of the abalone production and give insight into the amount of nutrient discharge from the facility.

#### 2.2.1. Sample collection

Water samples were collected from sea inlets and outlets of the facility at 8 occasions from 4 locations (fresh seawater after filtration, experimental tank (density experiment), D-1-3 tank, and fresh seawater before filtration (1 sample)). Samples for chemical discharge measurements were collected in 1 L plastic bottles that had been rinsed with 10% HCl and dried. Samples for microbial discharge measurements were collected in autoclaved 1 L plastic bottles, transferred to Matis on the same day and always analysed within 24 h.

### 2.2.2. Chemical discharge measurements

Measurements were performed at the NMÍ (Nýsköpunarmiðstöð Íslands) laboratory

The following parameters were measured:

- TAN (Total Ammonia Nitrogen)
- NO<sub>2</sub>-N
- NO<sub>3</sub>-N
- PO<sub>4</sub>-P
- Particulate nitrogen
- Particulate phosphorus

### 2.2.3. Microbial discharge measurements

Microbial counting was performed at the accredited laboratory at Matís. The following microbes were counted according to accredited methods:

- Cholera bacteria (ISO 9308-1:1990 & ISO 9308-1:2000)
- *E.coli* (ISO 9308-1:1990 & ISO 9308-1:2000)
- Salmonella (NMKL 71, 5 ed.1999/ISO 6579:2002)
- Total microbial count in 1 mL (SM, 23. ed.2017, 9215B & ISO 6222:1999 mod.)
- Total microbial count on marine agar in 1 mL

## 2.3. Nutritional value and contaminants

Samples of market size animals were submitted to the for analysis of nutritional value (fat, protein, carbohydrates, minerals and fatty acid profile) and level of chemical contaminants such as mercury, lead, cadmium and arsenic.

### 2.3.1. Sample collection and sample preparation.

Thirty animals in market size (40 g) were collected in a plastic bag and transferred to Matís on ice on the same day as they were collected. At the Matís laboratory the edible part of the animals was taken out of the shell and lyophilised and subsequently homogenised.

### 2.3.2. Analysis of nutritional value

The following nutritional factors were measured in abalone at the food research laboratory at Matís according to accredited methods:

- Fat (AOCS Ba 3-38 (2017))
- Protein (ISO 1663-1 (2008))

- Carbohydrates (ISO 5984 (2002))
- Salt (NaCl) (AOAC (2000). 17th ed no.976.18)

#### 2.3.3. Fatty acids analysis

Fat extraction is based on the Bligh and Dyer (1959) method. Methylation of the fatty acids is based on the Official AOCS method Ce 1b-89 with modifications. Fatty acid methyl esters (FAMES) were determined using GC-FID and parameters based on AOAC method 996.06.

#### 2.3.4. Heavy metals analysis

Heavy metals mercury (Hg), lead (Pb), cadmium (Cd), and arsenic (As) were quantified at Mátis laboratory using ICP-MS according to accredited method NMKL 186 (2007) with modifications.

## 3. Results and Discussion

### 3.1. Smart solutions for scale-up

#### 3.1.1. Model to maximise utilisation of rearing tanks within a manufacturing facility

The grow-out facility contains an intensive aquaculture in tanks, using a recirculating system and needs to be able to produce 200 tons of abalones each year. To simplify the facilities layout design process, systematic manual techniques based on systematic layout planning were used. Starting with defining the problem by setting the purpose, the goal, and the scope of the project. To get a good knowledge of the processes, the machines, the flow of the product and the communications between employees, the process was drawn using the BPMN standard. To be able to project the employee count for the new facility a time study was done of the grow-out process. The facility was then divided up based on information from the processes and the present facility. To find a good location for each division a relationship chart was created, and an activity relationship diagram drawn. The space requirements of each division were added to the diagram creating a space relationship diagram which was used to create several block layouts. The block layouts were then evaluated with regards to their material flow, space requirements and adjacency score and the block layout with the highest score was selected. The results include an improved pre-architectural design for a new grow-out rearing facility for Sæbýli ehf. which can be used to create a final design of a grow-out rearing facility for abalones. This work will also benefit the future plans of Sæbýli in promotional materials for investors.

#### 3.1.2. Prototype of a surveillance system implemented

Automatic sensors are important for new production facilities to minimise labour intensive interventions during farming.

To increase efficiency of the monitoring of abalone growth, by changing from manual to automatic measuring, an automatic measuring equipment was investigated. The measurements are performed by employing computer vision to a photograph of abalone. In principle, a few abalone are lined up on a photo table next to a reference item of known dimensions and a photo is taken with a camera that is above the photo table. Next, a software will calculate the dimensions of the abalone and deliver the results to the user.

Automatic monitoring of environmental factors in the farming system was also investigated. Léttbands system was tested but not implemented, instead, equipment was installed in collaboration with Samey to monitor in real-time parameters such as temperature, salinity and pH.

### 3.2. Green production – competitive edge

This part of the project was aimed to providing a competitive edge against competitors on the market by defining a “green production” strategy. Information and data were collected to support that the SustainCycle production has low environmental impact. This information is further important for stakeholders in the communities where future expansion is foreseen.

#### 3.2.1. Chemical discharge

The significance of N and P for aquaculture systems is highlighted based on environmental impact, as both N and P are the main ecosystem pollutants in aquaculture effluents. Table 1 shows the results for the discharge parameters analysed in the SustainCycle facility effluents.

**Table 1. Total Ammonia Nitrogen (TAN), NO<sub>2</sub>-N, NO<sub>3</sub>-N, PO<sub>4</sub>-P, particulate nitrogen and particulate phosphorus) in SustainCycle facility effluents.**

	Ammonium NH <sub>4</sub> <sup>+</sup> mg/mL	Nitrite NO <sub>2</sub> <sup>+</sup> mg/mL	Nitrate NO <sub>3</sub> <sup>+</sup> mg/mL	Phosphate PO <sub>4</sub> <sup>+</sup> mg/mL	Particulate P PP µg/mL	Particulate N PN µg/mL
<b>Date and sample</b>						
<b>19.Feb.19</b>						
Influent a. filtration	0.08	0.0012	0.043	0.0077	0.14	2.2
Density tank	0.097	0.04	0.337	0.067	11.7	132
D1-3	0.125	0.0098	0.727	0.078	124	81.2
<b>1.April.19</b>						
Influent a. filtration	<0.11	0.00081	0.049	0.0087	0.048	<1.25
Density tank	<0.11	0.042	0.372	0.056	29.3	136
D1-3	<0.11	0.011	0.502	0.102	13.7	248
<b>13.May.19</b>						
Influent a. filtration	<0.11	0.00077	0.021	0.0054	0.5	4.5
Density tank	<0.11	0.0307	0.411	0.086	5.8	59.2
D1-3	0.173	0.027	2.53	0.269	321	408
<b>4.June.19</b>						
Influent a. filtration	<0.11	0.00083	0.0091	0.0091	0.16	3.4
Density tank	0.333	0.11	0.966	0.0099	16.9	102
D1-3	0.17	0.038	2.05	0.147	117	207
<b>2.July.19</b>						
Influent a. filtration	<0.11	0.0011	0.011	0.011	0.56	9.8
D1-3	<0.11	0.013	0.636	0.051	92.6	217
<b>9.Aug.19</b>						
Influent a. filtration	<0.11	0.0014	0.026	0.008	0.35	3.6
D1-3	0.13	0.053	2.13	0.192	1056	855
<b>4. Sept.19</b>						
Influent a. filtration	<0.11	0.00081	0.017	0.0064	0.49	7.4
D1-3	0.141	0.018	1.2	0.05	238	459
<b>10. Oct.19</b>						
Influent b. filtration	<0.11	0.0025	0.057	0.0076	1.23	26.6
Influent a. filtration	<0.11	0.0007	0.036	0.011	0.35	3.5
D1-3	0.148	0.026	1.5	0.07	222	419

The Environment Agency has based the discharge limits for aquaculture on an article by Wang et al. (2012) which aquaculture operators generally rely on when presenting results on emissions due to aquaculture.

In the case of aquaculture with effluent discharge into the sea, only the limit for phosphorus is required and is based on the feeding factor 1.2 (Petersen SA et al. 2005, Reid et al. 2009) and the limit has recently been changed to 10 kg phosphorus/tonne of biomass increase per year.

When discharging into fresh water, the limit for nitrogen is set at 60 kg/tonne of biomass increase per year. But if the effluent is filtered, only the dissolved substances should be discharged, and this limit is therefore quite high if that is the case.

According to the results in Table 1, the highest concentration of dissolved phosphorus is 0.269 mg/L in effluent from system D1-3 on 13 May 2019. In system D1-3, the biomass went from 100 kg to 404 kg in one year. The increase in biomass was therefore 304 kg in the continuation system D1-3. Water consumption in the system was 5 L/minute, which is calculated at 2,563,000 L/year.

The maximum discharge of dissolved phosphorus from system D1-3 has been calculated using the following formula:

$$\frac{(0.000000269 \text{ (kg P)/L})}{(0.304 \text{ tonne biomass increase}) \times 2563000 \text{ L / year}} = 2.3 \text{ kg phosphorus/tonne biomass increase per year}$$

Compared to the discharge limit values from the Environment Agency, 10 kg phosphorus/tonne of biomass increase per year, the measured maximum concentration of phosphorus in the SustainCycle effluent, 2.3 kg phosphorus/biomass increase per year, is well within limits.

As can be seen from the results in Table 1, there are large fluctuations in the concentration of both solutes and particulates. This difference can depend on various factors e.g. timing of feeding, timing of sampling, biomass during sampling and other factors.

### 3.2.2. Microbial discharge

Table 2 shows the results for microbial counts performed on water samples taken monthly during the period February 2019 to October 2019. One sample was taken of fresh seawater before filtration and UV treatment. Unfortunately, due to human error, the animals in the experimental tank (density experiment) died. No more samples could be taken from that system after 4 June.

**Table 2. Results for microbial count in SustainCycle facility effluents. TAMC = Total Microbial Count**

<b>Date and sample</b>	<i>E.coli</i>	<i>Salmonella</i>	<i>Coliforms</i>	<b>TAMC in 1 mL</b>	<b>TAMC in 1 mL marine agar</b>
<b>19.Feb.19</b>					
Influent a. filtration	0	negative	0		
Density tank	0	negative	0		
D1-3	0	negative	0		
<b>1.April.19</b>					
Influent a. filtration	0	negative	0	0	
Density tank	0	negative	0	87	
D1-3	0	negative	0	37	
<b>13.May.19</b>					
Influent a. filtration	0	negative	0	2	6
Density tank	0	negative	0	230	19000
D1-3	0	negative	0	370	31000
<b>4.June.19</b>					
Influent a. filtration	0	negative	0	1	8
Density tank	0	negative	0	480	>2500
D1-3	0	negative	0	450	45000
<b>2.July.19</b>					
Influent a. filtration	0	negative	0	0	27
D1-3	0	negative	0	520	1200000
<b>9.Aug.19</b>					
Influent a. filtration	0	negative	0	0	0
D1-3	0	negative	0	95	87000
<b>4. Sept.19</b>					
Influent a. filtration	0	negative	0	0	0
D1-3	0	negative	0	41	160000
<b>10. Oct.19</b>					
Influent b. filtration	0	negative	4	13	520
Influent a. filtration	0	negative	0	0	0
D1-3	0	negative	0	210	220000

Table 3 shows the environmental limits for microbial contamination in surface water for outdoor activities, according to Art. Regulation no. 796/1999 for faecal contamination and is considered acceptable if waters fall into categories I-II (see further on environmental limits for different substances in annex to Regulation No. 796/1999). The limit value for faecal coliforms in surface water for outdoor activities is 100/100 mL. There are no regulatory limits on environmental microorganisms.

**Table 3. Environmental limits for faecal coliform contamination in surface water for outdoor activities (Reykjavik Health Authority).**

<b>Category</b>	<b>Condition</b>
I	Very little or no faecal coliform contamination (<14/100 mL)
II	Little faecal coliform contamination (14-100/100 mL)
III	Some faecal coliform contamination (100-200/100 mL)
IV	Heavy faecal coliform contamination (200-1000/100 mL)
V	Unsatisfactory water condition (>1000/100mL)

Compared to these limit values, faecal coliforms in Sæbýli's abalone aquaculture are always below the limit, in addition to which there are no signs of pathogens such as *E. coli* or Salmonella. The only sample measured with any faecal coliforms was in the influent seawater. All other samples taken were negative.

The number of bacteria in 1 mL per PCA (plate count agar) is lower than on MA (marine agar) which is normal, as MA contains salts and other ingredients from the sea that PCA does not and thus better supports the growth of microorganisms expected in seawater samples.

However, these figures are higher in the tanks than in the influent seawater, using a comparable methodology. This is normal, given the concentration of animals in a closed system. The highest counts occur during the high summer, the question is whether the warmer months push for higher counts, but this does not have to be the case if the temperature in the systems is constant throughout the year. There is no doubt that there is a great deal of inter-day variation in counts as well and when the samples are taken.

Figure 1 shows the results of counts of samples taken in 2013, in another project. Compared with counts of samples taken in 2019, this is in a similar range as in terms of the number of bacteria on MA.

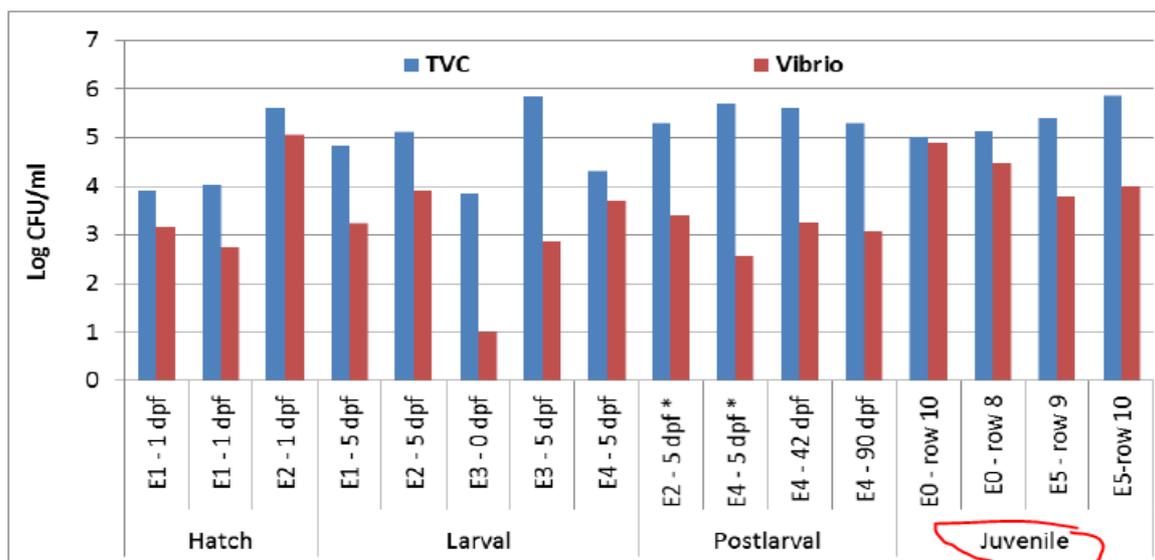


Figure 1. Total microbial count (TVC, MA, 17°C) together with Vibrio counts (mTCBS, 17°C) in samples from breeding systems in Sæbýli. The samples were taken from fertilisation and up to older individuals. Results are from different experiments (E0, E1, E2, E3, E4 and E5). Numbers are in log, i.e. log 5 corresponds to 100,000 CFU/mL. Dpf stands for "days post fertilisation".

### 3.3. Nutritional value and contaminants in abalone produced in Iceland

Data was obtained to demonstrate that the SustainCycle product is superior with regards to nutrition, and low levels of contaminants in comparison to literature data from productions abroad (e.g., in Asia).

#### 3.3.1. Nutritional value and fatty acid composition

Table 4 shows the results for the nutritional value of abalone after 2.5 years of growth.

**Table 4. Nutritional components measured in SustainCycle abalone after 2.5 years of growth.**

Nutritional parameter	Analytical method	Measured value	Uncertainty
Protein	(Nx6.25)DUMAS (AE8)	11.9%	2%
Fat	Soxhlet (AE1)	0.4%	17%
Ash	AE5	2.5%	11%
Salt NaCl	AOAC-Titrino (AE2)	1.9%	9%
Salt NaCl	Calculated from chloride		
Water		83.1%	
Carbohydrates		2.1%	

Table 5 presents the results for the fatty acid analysis of abalone in market size.

**Table 5. Fatty acid composition of SustainCycle abalone in market size. The ratio of fatty acids in lipids.**

Fatty acid	% fatty acid methyl esters	Fatty acid	% fatty acid methyl esters
C12:0	0.6	C18:3n3	1.4
C14:0	4.6	C18:4n3	n.f.
C14:1	0.3	C20:0	n.f.
C15:0	1.4	C20:1(n11+n9)	8.0
C16:0 (Palmitic acid)	22.6	C20:3n3	0.3
C16:1n7	1.8	C20:4n6	n.f.
C16:2n4	1.2	C20:4n3	n.f.
C17:0	n.f.	C20:5n3 (EPA)	4.0
C16:3n4	0.4	C22:1(n11+n9)	7.5
C17:1	n.f.	C22:2	1.9
C18:0	4.6	C22:4n6	n.f.
C18:1(n9+n7)	14.7	C22:5n3	0.4
C18:2n6	3.6	C22:6n3 (DHA)	3.9
C18:3n6	n.f.	C24:1n9	2.9
SFA	32.5	MUFA	35.2
PUFA	17.1	Total omega-3	11.9

According to these results, abalone are a healthy product, with about 12% protein and low-fat content (0.4%) where the majority are unsaturated fatty acids and about 12% of the total lipid content are Omega-3 fatty acids.

Compared to species with a high lipid content in the flesh (e.g., salmon), abalone are not a rich source of Omega-3 fatty acids (Mulvaney et al. 2015).

### 3.3.2. Heavy metals content

Table 6 shows the results for the heavy metal analysis (mercury (Hg), cadmium (Cd), lead (Pb) and arsenic (As)) in ppm per wet weight in abalone in market size from Sæbyli.

**Table 6. Amount (ppm) of heavy metals (mercury, cadmium, lead and arsenic) per wet weight in abalone.**

Heavy metal	Measured value	Uncertainty
Mercury (Hg)	0.056 mg/kg	30%
Cadmium (Cd)	0.12 mg/kg	20%
Lead (Pb)	<0.012 mg/kg	20%
Arsenic (As)	1.2 mg/kg	20%

Commission Regulation (EC) No 1881/2006 on "maximum levels for certain contaminants in food" does not contain maximum levels for heavy metals in abalone but compared to maximum levels (Table 7) for species such as shellfish, sandwiches and squid, the levels of heavy metals in the abalone from Sæbýli are always far below those limits. Maximum levels for arsenic are only set for feed and rice.

## 4. Conclusion

Based on the results obtained in this project, it can be stated that there is little to no environmental impact from the production of abalone in vertical large-scale farming, considering the discharge of nutrients and microorganisms in the effluent from the operation. Measurements of wastewater from the facility show that biofiltering and reuse of indoor water returns unpolluted water back into nature. Factors that were measured in regular sampling over the project period were bacterial count, ammonia, nitrite/nitrate, phosphorus and particulates. Nevertheless, it is recommended that the amount of phosphorus in the effluent be monitored regularly.

Pre-design and drawings for a new 200 tonnes production site are ready, together with a cost and operating plan. Smart solutions were tested and implemented for upscaling, e.g., introduction of new ways to control the acidity of aquaculture water, increased knowledge of the maximum utilisation of biofilters in the aquaculture system, as well as the development of automatic equipment to measure the growth rate of aquaculture animals. Measurements of nutritional parameters and undesirable substances show that abalone are rich in protein and low in fat and far below regulatory limits for heavy metals as mercury, lead, cadmium, and arsenic.

Based on the results of the project Sæbýli's infrastructure has been strengthened with operating procedures, training and disease prevention and a Veterinary Health Plan (VHP) for livestock and the operation of Sæbýli is being prepared.

Furthermore, results from the project were used to prepare marketing material for pristine abalone production in Iceland. This included a flyer for a broader audience e.g., investors and communities interested in building up abalone production. This has led to increased cooperation with domestic parties with an emphasis on the experience of consuming abalone in Icelandic restaurants, e.g., Nostra, Apotekið, Hosiló and Aalto Bistro have in one way, or another offered abalone on their menu.

A new business plan based on the above work components has been made and new premises in Grindavík have been taken into use for roe and juvenile production.

## Acknowledgements

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## References

Bligh, E.G. and W.J. Dyer. (1959). "A rapid method of total lipid extraction and purification." *Canadian Journal of Biochemistry and Physiology*, **37**(8): 911-917.

Mulvaney, W.J., S. Jahangard, B.A. Ingram, G.M. Turchini and P.C. Winberg. (2015). "Recovery of omega-3 profiles of cultivated abalone by dietary macroalgae supplementation." *Journal of Applied Phycology*, **27**(5): 2163-2171.

Petersen S.A, Sutherland TF and H. D. (2005). "Physical and chemical characterization of salmonid feed pellets." Canadian Data Report of Fisheries and Aquatic Sciences 1159. Fisheries and Oceans Canada, West Vancouver, BC.

Reid, G.K., M. Liutkus, S.M.C. Robinson, T.R. Chopin, T. Blair, T. Lander, J. Mullen, F. Page and R. Moccia. (2009). "A review of the biophysical properties of salmonid faeces: implications for aquaculture waste dispersal models and integrated multi-trophic aquaculture." *Aquaculture Research*, **40**(3): 257-273.

Wang, X., L.M. Olsen, K.I. Reitan and Y. Olsen. (2012). "Discharge of nutrient wastes from salmon farms environmental effects, and potential for integrated multi-trophic aquaculture." *Aquaculture Environment Interactions*, **2**(3): 267-283.