

## Slutrapport

**Sustainable animal feed with algae and mussels**

**Projektnummer: O-15-20-559**

**Projektperiod: 2016-01-31 till 2018-12-31**

**Huvudsökande: Catherine Legrand, Linnéuniversitetet (Lnu),  
catherine.legrand@lnu.se**

**Medsökande:**

**Elin Lindehoff (PhD, Lnu)**

**Lina Mattsson (doktorand, Lnu)**

**Magnus Elfving (PhD, Lnu)**

**Eva Pohl (doktorand, Lnu)**

**Kimberly Berglöf (masterstudent)**

**Anna Thore (WSP)**

**Rejne Erixon (Swedish Agro)**

**Jan Andersson (Jan Anderssons dykeri)**

**Magnus Algotsson (Veterinär, Guldfågeln AB/Lnu)**

**Karin och Jonas Lundqvist (Voxtorpsgården, ekologiskt lantbruk)**

Projekt har fått finansiering genom:

## Del 1: Utförlig sammanfattning

Visionen med projektet är att undersöka potentialen hos lokalt producerade mikroalger och blåmusslor som hållbar proteinkälla i foder till värphöns och därmed minska beroendet av importerade soja. Mikroalger har goda förutsättningar att fungera som proteintillskott då protein och oljeinnehåll liknar det hos sojaböner. Musselmjöl har potential att ersätta fiskmjöl som proteinkälla i ekologisk äggproduktion. Att använda alger och musslor i foder bidrar till en hållbar utveckling och begränsar övergödning och växthuseffekt. Mikroalger kan produceras i sydöstra Sverige genom att återanvända koldioxidutsläpp från förbrännings- och biogasanläggningar och återvinna näringsämnen ur processvatten. Musselodling fungerar som en näringsränna vid skörd och motverkar lokal övergödning. Projektet har genomförts som en branschöverskridande samverkan där forskare, foder- och värphönsindustrin har fördjupat kunskaperna kring hur importerat sojafoder kan minskas med en lokalproducerad proteinresurs.

Projektet demonstrerar att det är genomförbart att använda lokalt producerade mikroalger och blåmusslor som proteinkälla/tillskott i foder till värphöns. Det bekräftar att: storskalig odling av mikroalger är möjligt i sydöstra Sverige; att odlingar av blåmusslor kan producera upp till 90 ton musslor per hektar och år om skörd görs under optimala förhållanden under tidig vår och; att den studerade musselodlingen i Hagby, Kalmarsund inte hade någon negativ inverkan på omgivande vatten, jämfört med en referenslokal.

I småskaliga födoförsök med ekologiska värphöns har de marina substraten 1) hela, torkade och krossade blåmusslor, 2) musselmjöl (köttet från musslan i torkad form) och 3) algiomassa testats i tre separata försök som fodertillskott åt två testgrupper (10 individer vardera) jämfört med en kontrollgrupp (10 individer) som givits ekologiskt standardfoder. Resultaten visar att i samtliga försök bibehölls äggen kvalitet (näringssinnehåll), säkerhet (halter av metaller och biocider under riktvärden) och produktion (antal ägg per höna) när hönsen fick äta ovanstående marina substrat. I försök 1) testades även skal från blåmusslor som kalkkälla till värphöns, vilket visade sig ge likvärdig brottstyrka och skaltjocklek som hos kontrollgruppen. Hönsen uppvisade också en lägre grad hack-beteenden när krossade blåmusslor fanns att äta. Smakpaneler av skiftande bakgrund och ålder har erbjudits smaka ägg (blindtest) från test- respektive kontrollgrupp under försöken och ingen skillnad i smak kan avgöras mellan grupperna. Dock upplevs textur och äggulans färg bättre när hönan ätit marina substrat.

Projektet levererar ett första så kallat *proof-of-concept* att mikroalger kan användas som proteinkälla i hönsfoder och att blåmusslor från Östersjön kan utgöra ett alternativ till fiskmjöl i foder till ekologiska värphöns. Konceptet är nu redo för nästa nivå där de marina substraten testas i stor skala under hela värphönans livstid.

## **Del 2: Rapporten (max 10 sidor)**

### **Inledning**

The vision is to reduce imported soybean and develop a sustainable and locally produced animal feed from marine substrate such as microalgae and blue mussels for the poultry industry. Microalgae have a good potential to be a feed ingredient since they have high protein and oil levels. Mussel meal can replace a part of soy in poultry diet or fish meal in organic poultry production. Microalgae and mussels both contain the essential dietary amino acids (lysine, methionine, cysteine) and could reduce the need to supplement synthetic amino acids to meet requirements in chicken feed.

Using microalgae and mussel meal in animal feed contribute to sustainable development, and eutrophication and climate change mitigation efforts. Microalgae can be produced in Southeast Sweden, recycling carbon dioxide from industrial flue gas, and recovering nutrients from various waters. Mussel farming can act as a nutrient sink in the Baltic Sea and reduce local eutrophication.

### **Challenges for livestock production**

Among the future challenges facing the poultry industry to 2020, food safety and issues related to nutrition and feeding are crucial to address. Today, the poultry feedstuffs depend heavily on imported soybeans whose production is connected with rain forest destruction, the use of dangerous pesticides, questionable working situations, long transport, health concerns for both humans and birds, and food security. Soy is an excellent protein source and it is available, thus little work has been done to find other substitute ingredients adequate for poultry diets and locally produced. In organic egg production fish meal is used as an alternative to soy. The use of fish meal with high amounts of PCBs and dioxins lead elevated levels of toxicant in the eggs compared to non-organic eggs (Livsmedelsverket 2016).

### **Algae and mussels are suitable animal feed ingredients**

Soybean meal is one of the richest sources of plant protein but both microalgae and mussels can be used as high protein animal feed or aquafeed (fish) (Box 1). Algae and mussels both contain the amino acids (methionine, cysteine, lysine) essential for poultry diets but their metabolisable content is unknown. Algae also have high levels of carotenoids (some of which with vitamin A activity), more oil (30-40%) and a high proportion of polyunsaturated fatty acids such as Omega-3 and Omega-6 than can be transferred from hen to eggs, increasing the nutritional value (Box 1). Mussels are also a great source of calcium, which is important for the development of birds and eggs. Recently, the Swedish Food Agency (Livsmedelsverket) has approved the use of blue mussels (*Mytilus edulis*) from the Kattegat and the Western Baltic Sea as a feed ingredient for broilers and egg laying hens. The Swedish organization KRAV (organic standards label) recommends blue mussels for aquafeed (instead of fish meal). However, little is known about the composition of mussels grown in the coastal Baltic Sea (east coast of Sweden, Kalmar sound).

<b>Box.1 Composition of algae and mussels compared to standard supplement in animal feed (soy).</b> Algae data: Baltic Sea, Mussel data: Kattegat			
	Algae biomass <sup>1</sup>	Mussel meal <sup>2</sup>	Soy
Ratio wet: dry	2.5:1	20:1	n/a
Protein g DW kg <sup>-1</sup>	210-360	764 <sup>8</sup>	520 <sup>2</sup>
Protein % DW	20-40	30-70	40 <sup>2</sup>
Met-Cys % Prot	1-3 <sup>3,4</sup>	2.5	1 <sup>2</sup>
Lysine % Prot	2-7 <sup>3,4</sup>	4.2	2.9 <sup>2</sup>
Lipids	25-40	8	15-20 <sup>5</sup>
Omega-3 fatty acids (% Lipids)	20-40 <sup>6,7</sup>	< 10% <sup>5</sup>	20 <sup>5</sup>

<sup>1</sup>ALGOLAND, unpubl. data; <sup>2</sup>Berge and Austreng, 1998, <sup>3</sup>Leveille et al. 1960, <sup>4</sup>Holman et al. 2012, <sup>5</sup>WHO, <sup>6</sup>Olofsson et al. 2012, <sup>7</sup>Adarme-Vega et al. 2012, <sup>8</sup>Lindahl 2013

### Algae, mussels and food safety

Algae and mussels grown in the Baltic Sea region (with Baltic Sea water) were tested for critical trace elements and other contaminants (Box 2). All tested elements in algal biomass were well below safety levels for the use of non-fuel products, such as animal feed and fertilizer, and feed for biogas (Legrand et al. unpubl.). All four critical elements in blue mussels were below safety levels assuming that mussel meal will make up <10% of the animal feed. Tests for toxic elements showed no substantial contamination of dioxins in algal biomass grown with industrial flue gas, at the cement plant in Degerhamn (CementaHeidelberg, ALGOLAND project). Both algae and mussel could make a successful addition to poultry diets but it remains to be tested under practical conditions.

<b>Box. 2 Critical elements in Algae and Mussels from the Baltic Sea/Kalmarsund</b>						
Element	Industrial flue gas biomass (mg kg <sup>-1</sup> )	Reference biomass (mg kg <sup>-1</sup> )	Baltic blue mussels <sup>5</sup> (mg kg <sup>-1</sup> )	Safety levels		
				Animal feed (mg kg <sup>-1</sup> )	Fertilizer (mg kg <sup>-1</sup> )	Biogas production
Hg	<0.2	<0.05	2	0.5 <sup>2</sup>	2.5 <sup>1,2</sup>	
Cd	<0.002	<0.02	1.5-2	1-2 <sup>2</sup>	2 <sup>1,2</sup>	<1500 <sup>3</sup>
As	<1	<1	15	10 <sup>2</sup>		
Pb	<1	<0.5	2.5	5 <sup>2</sup>	100 <sup>2</sup>	<600 <sup>3</sup>
Cu	<30	<20			600 <sup>1,2</sup>	<2000 <sup>3</sup>
Ni	<1	<2			50 <sup>1,2</sup>	<1000 <sup>3</sup>
Zn	<40	<40			800 <sup>1,2</sup>	<800 <sup>3</sup>
Cr	<1	<1			100 <sup>1,2</sup>	
S	<7000	<7000				<30 000 <sup>4</sup>

<sup>1</sup>Kollberg & Ljungqvist 2005<sup>1</sup>, <sup>2</sup>EU directives, 1986, <sup>3</sup>Jain et al. 1991, <sup>4</sup>Briand and Morand 97, <sup>5</sup>Rüdel et al. 2010

### Conservation of natural resources and ecosystem services

Using locally produced algae and mussels in poultry and aquafeed provide additional environmental benefits compared to soy. Farming algae is possible in the Baltic Sea Region (Olofsson 2015). This technology can be used to scrub carbon dioxide in industrial plants or farms, help to treat waste water or run-off that contains ammonia or phosphorus e.g. poultry houses. Algal biomass can be further processed into high value products concentrate for food/feed applications, cosmetics or energy. Farming mussels

requires no additives to the water, feed or medicine, and these filter feeders get all the food (plankton) they need from the sea. In the coastal Baltic Sea, mussel production can be used to combat local eutrophication e.g. capture nutrients in the form of plankton ingested. Upon harvest and process into animal feed or fertilizer, the mussels contribute to recover phosphorus (limited resource). Ongoing efforts in the Baltic Sea are currently examining nutrient uptake, cost-effectiveness, and potential environmental impacts of mussel farming as a means to mitigate eutrophication and complement traditional wastewater treatment programs (Baltic Blue Growth project<sup>1</sup>).

### **Aim**

The overall objective of this project is to demonstrate the feasibility of using locally produced microalgae and blue mussels as supplement in poultry feed. We will 1) perform small scale trials for the testing of the effect of feed composition (10-15% algal biomass, whole blue mussels or mussel meal) on production performance of egg laying hens, 2) define and assess operational risks associated to the local supply chain of algae and mussels, 3) provide sustainability indexes to support the development of seawater farming and improvement of the poultry industry, and 4) raise awareness amongst stakeholders, specifically farmers and seafarmers, and the local population.

### **Project group**

In the proposed project, representatives from Linnæus University, the mussel- and poultry industry (Jan Andersson Dykeri, Voxtropsgården), the animal feed industry (SwedishAgro) and the extension services organisations (Kalmarsunds Kommissionen, WSP) join in a multidisciplinary collaboration to deepen the knowledge of using microalgae and mussels as ingredients in poultry feed. A reference group including other stakeholders (farmer, LRF, Kalmar Energy AB, County Administration Board in Kalmar County, Linnæus University) will provide input and support for decisions in the project. Communication strategy includes raising the awareness amongst current/potential users (farmers, seafarmers) of a more sustainable animal feed and local population to continuously support and maintain such initiatives.

## **Materiell och metoder**

### **Workplan and organization**

The project was divided into 4 different Activities 1) Algal production; 2) Blue mussel production; 3) Poultry feeding trials; 4) Sustainability indices. Activities has been run at three test-sites, Degerhamn (algal farm), Hagby (mussel farm) and Voxtropsgården (feeding trail using egg laying hens).

The project activities are rooted in different projects, of which ALGOLAND<sup>2</sup> (umbrella program) serves as a structure to expand our field of research in algal applications at Linnæus University and the Baltic Blue Growth project, which is an EU funded effort to

<sup>1</sup> BalticBlueGrowth <https://www.submariner-network.eu/projects/balticbluegrowth>

<sup>2</sup> ALGOLAND (<https://lnu.se/algoland>) was cited as an example of excellent research with societal impact at the national level by the Swedish Research Council evaluation of the Strong Research Environment [Ecochange](#).

establish operational mussel farms to counteract eutrophication and create new blue growth opportunities.

### **Activity 1 – Algal production**

The ALGOLAND bioreactor in Degerhamn, Öland SE Sweden is a flat panel GWP-II reactor (Fotosintetica & Microbiologica s.r.l (F&M), Florence, Italy) in operation since 2014. In June 2016 the bioreactor was doubled in size from 4 to 8 12 m panels in a total volume 3.6 m<sup>3</sup>, to enable production of biomass for feeding trials. An industrial centrifuge (AlfaLaval) was installed on site in Degerhamn during 2017 to increase harvest efficiency. The Degerhamn reactor has been operational 2016-2018 approx. from March to November. Temperature, dissolved oxygen (DO) and pH of the algal culture were monitored continuously by logging and remote transfer of data. The culture was aerated by compressing ambient air. Cement flue gas (CementaAB, Degerhamn) containing 12-15 % CO<sub>2</sub>, was introduced at the high pH setpoint of 8.0. Nutrients were added in, for algal growth, unlimited concentrations. Harvest of biomass was carried out 3 times a week using the industrial centrifuge and concentrated biomass was immediately frozen until dried (50°C) for use in feeding trial (Activity 3) or analysis of nutritional value or toxicity screens (analysed by ASL).

### **Activity 2 – Blue mussel production**

Optimal harvest time of Baltic Sea Blue mussels for maximum environmental service and biomass gain.

Water quality was measured at the Hagby mussel farm (in Kalmar sound) and a reference site, close-by of similar depth and characteristics during 15 months in 2016 – 2017. Sampling included dissolved and particulate nutrients, Chl a, CDOM and background data (salinity, temperature) and was monitored weekly. Mussel settling, biomass and condition index at the farm was measured monthly.

### Blue mussel biomass used in poultry feeding trial

Harvested mussels, delivered to the project by collaboration partner BBG

- Västervik mussel farm, harvested 2-3 yr old blue mussels in 2016, used as dried (70°C short interval and then 40°C until dry) and churched in feeding trials 1- Mussel meat and shell.
- Västervik mussel farm, harvested 2-3 yr old blue mussels in 2016, shell and meat was separated by lysis and mussel meal used in feeding trial 2 – Mussel meal 1
- St Anna mussel farm, harvested 1-2 yr old blue mussels in 2018, shell and meat was separated and mussel meal used in feeding trial 4 – Mussel meal 2

### **Activity 3 – Poultry feeding trials**

Deviation from the original plan in application to SLF:

2016 - 12 - 31: Chicken producer Guldfågeln AB is no longer a partner in this project due to divergent priorities regarding the feeding trials of broiler chicken. This SLF project is a pilot project and cannot guarantee the delivery of algal+mussel biomass for pre-commercial feeding trials. After discussion with the project reference group (Swedish Agro, Kalmar municipality, Cementa Degerhamn, Region Kalmar, Kalmar

County Administrative Board, Water Delegation of South West Sweden, Kalmar Science Park, Västervik municipality), the project leadership (LNU) agreed to focus on feeding trials with egg laying hens instead of broiler chickens. The change enables the project to evaluate blue mussel shells as calcium source in feed for hens. Organic egg producer Voxtorpsgården (Karin and Jonas Lundqvist) is new partner for feeding trials to be performed in 2017-2019 when risk assessment and quality control have been completed.

#### Feeding trials

Feeding trials were performed at Voxtorpsgården using 3 group of hens in identical enclosures (indoor app. 5m<sup>2</sup>, outdoor app. 15m<sup>2</sup> with 10 hens in each. Group A and B where given feed with mussel or algae as supplement (see trials description below) and group C standard feed for organic egg production. Aim of the trials was to test blue mussels and algae as calcium and/or protein source for hens with focus on egg-production and quality.

- Trial 1- mussel meat and shell (2018, duration: 3 months). In test group A+B whole dried and crushed blue mussel where mix to 15% in standard organic feed (Swedish Agro) for egg laying hens, calcium supplement of 15% removed. Control group C received standard organic feed (Swedish Agro). Eggs were counted, collected and sent for analyses of egg parameters (egg weight, shell strength, color of yolk, shell weight and thickness (analysed by SLU) and nutritional and toxicity analysis (ALS).
- Trial 2- mussel meal 1 (2018, duration: 1 month) In test group A+B mussel meal was mixed to 7.5% (to replace the portion of fish meal used in organic feed) in standard organic feed (Swedish Agro) for egg laying hens. Control group C received standard organic feed (Swedish Agro). Eggs were counted, collected and sent for nutritional and toxicity analysis (ALS).
- Trial 3- algal biomass (2018, duration: 1 month). In test group A+B dried algal biomass from the ALGOLAND photobioreactor in Degerhamn was mixed to 10% in standard organic feed. Control group C received standard organic feed (Swedish Agro). Eggs were counted, collected and sent for nutritional and toxicity analysis (ALS).
- Trial 4 – mussel meal 2 (2019, 3 months, ongoing) In test group A+B mussel meal was mixed in to 7.5% (to replace the portion fish meal used in organic feed) in standard organic feed (Swedish Agro) for egg laying hens. Control group C received standard organic feed (Swedish Agro). Eggs are counted and collected and sent for nutritional and toxicity analysis (ALS).

#### Egg tasting test

At several outreach events and conferences, the ALGOLAND team has offered visitors to taste eggs from Group A and B (mussel egg) compared to C (control egg) from Trial 1 and 2 without them knowing which egg came from a hen fed mussels (blindtest). Approximately 250 people has participated from the age of 18 to 70.

#### **Activity 4 – Sustainability indices**

Based on 3 years operations data from the Degerhamn system life cycle and cost assessments (LCA, LCC) was developed for scenarios varying in the use of sustainable resources and size.

### **Resultat och diskussion**

#### **Activity 1 – Algal production**

The project successfully harvested biomass in 2017-2018 to run feeding trial 3 (see method section above).

Highlights from conclusions based on sister- ALGOLAND project run in Degerhamn:

- Large-scale algal cultivation is possible and stable in SE Sweden from March – November.
- Multi-species approach using local Baltic Sea microalgae takes advantage of local adaptations to light and temperature
- Multi-species approach using local Baltic Sea microalgae show equal stability in production and quality (valuable products like proteins, lipids and carbohydrates) as fast growing single strains
- Microalgae can capture up to 60% of the CO<sub>2</sub> from added cement flue gas, without a loss of production

Process described in Olofsson et al. 2015, 2019 and in manuscripts no 2, 6, 8, 9, (see list under Del 3: resultatförmedling)

#### **Activity 2 – Blue mussel production**

##### Optimal harvest time of Baltic Sea Blue mussels for maximum environmental service and biomass gain.

The results show that the optimal time for harvest of Blue mussels in the Baltic Sea is early spring before spawning, which will generate maximum yield of mussel meat (20.05±0.65%), compared to late autumn/winter (11.01±2.36%) and nutrient removal from coastal waters. A harvest in early spring also reduced the risk algal biotoxins being present in the mussel meal compared to a harvest in late summer.

Extensive monitoring of Hagby mussel farm and a reference site revealed no direct effect of the mussel farm on water quality (Principal component analysis).

Based on monthly sampling of mussel biomass and condition index we conclude that the mussel farm can produce 60-90 tons mussels yr<sup>-1</sup>ha and if the farm is extrapolated to standard size (1ha, 10 lines of 100 m long and 10 m in depth) it could capture 600-900 kg of nitrogen and 60-90 kg of phosphorus each harvest.

Preparation of peer-reviewed publication is on-going (manuscript no. 3 under Del 3: Resultatförmedling).

#### **Safety and quality of Algal and mussel biomass**

Nutritional value, safety and quality of algal and mussel biomass (Activity 1 and 2) are assessed by in-house analyses of lipids, proteins and carbohydrates together with accredited analyses of fatty acid profiles, metal content, dioxins and other organic



toxins (by accredited lab, ALS). Analyses on harvested algal- and mussel biomass showed all harmful substances below safety levels and safe to use in feeding trials.

### **Activity 3 – Poultry feeding trials**

#### **Trial 1 – mussel meat and shell**

There was no difference in the amount of eggs produced per hen (ANOVA  $p > 0.05$ ), egg parameter, nutritional and toxicity analysis between group A and B (15% mixture of whole mussels) and the control group. From observations of the hens given whole blue mussel more time was spent foraging food (pieces of mussels) than engaged in picking behavior (on other hens). This inspired a spin-off project where the hens were filmed to analyze their behavior. Data is under analysis.

#### **Trial 2 – mussel meal 1**

There was no difference in the amount of eggs produced per hen (ANOVA  $p > 0.05$ ), nutritional and toxicity analysis between group A and B (7,5% mixture of algal biomass) and the control group. Toxicity screens confirm that blue mussels from the Baltic Sea could be an alternative protein source to the much-debated fish meal in organic egg production. The mussel meal was difficult to mix in with the feed and highly hydrophilic. A new mussel meal of improved structure has been delivered from BBG and currently tested in trial 4 (ongoing).

#### **Trial 3 – Algal biomass**

There was no difference in the amount of eggs produced per hen (ANOVA  $p > 0.05$ ), nutritional and toxicity analysis between group A and B (10% mixture of algal biomass) and the control group. Toxicity screens confirm that algal biomass could be an alternative to imported soy beans as protein source in egg production.

Preparation of peer-reviewed publication is on-going (manuscript no. 4 under Del 3: Resultatförmedling).

#### **Egg tasting test**

There was no statistical difference in appreciation of taste between mussel egg and control egg (t-test  $p > 0.05$ ). From the given comments it was clear that the mussel egg more often got the comment of a more yellow colored yolk and agreeable texture.

### **Activity 4 – Sustainability indices**

Life cycle assessment (LCA), life cycle cost assessment (LCCA) and societal impact is in progress. A first LCA- and LCCA model for microalgal production in Degerhamn was completed during 2017 and preparation of peer-reviewed publication is on-going (manuscript no. 10 under Del 3: Resultatförmedling).

The study showed that production costs can be lowered by 20% in large scale cultivation (>1ha) if the ALGOLAND methods of sustainable resource use is applied instead of traditional cultivation methods.

## Slutsatser

The project has demonstrated feasibility of using locally produced microalgae and blue mussels as supplement in poultry feed. First by confirming that: large-scale microalgal production in SE Sweden was proven feasible in large scale and enough for feed supplement production; and if harvested at optimal meat content Baltic blue mussel farms can produce 90 ton mussels yr<sup>-1</sup> ; and that the studied Hagby mussel farm showed no negative impact on water quality parameters compared to reference site. Further, analyses on harvested blue mussels and algal biomass showed all harmful substances below safety levels for use as feed supplements. The performed feeding trials using egg laying hens showed that egg safety, quality and production is maintained when fed whole blue mussels, mussel meal or algal biomass. The project can give a first confirmation and *proof-of-concept* that algal biomass can be used as protein source in poultry feed. And that blue mussel meal could be an alternative protein source to fish meal in organic egg production, with shells given as calcium source. The eggs from hens given mussel meal was described as of better color and texture compared to control eggs by tasting panels and there are indications that hens given crushed blue mussels engaged in less feather picking behavior.

## Nytta för näringen och rekommendationer

The vision of the project is to enable the approval of Baltic Sea algae and mussel meal as ingredients in poultry feed. The multidisciplinary approach of the project with feed suppliers and the poultry industry ensures that the safety and quality of the new feed ingredients will meet all the needs of the industry. Introducing an alternative to imported soymeal will allow the poultry industry to improve their ecological footprint and reinforce food security (global price and availability of soymeal). The poultry industry will be strengthened by the use of local/regional production of substitute ingredients rather than imported questionable soybean.

Today in the Baltic Sea, algae production and mussel farming are not economically viable because the business is still in its infancy. However, by developing a market for algae and mussel meal the project can help to make algae farming and mussel farming more profitable. Through continuous collaboration with scientists in this project, this up-and-coming (sea-farming) business sector can be helped to improve the nutritious quality and safety of their products, optimize the harvest season, and be reassured that the products are free from any hazardous substances. Together with other projects that focus on the efficiency of the farming process this will lead to a marine product that will in time be profitable.

## Future research and development needs

- A cost-efficient way to separate mussel meat and shell, with a final product of homogenous and good structure. Not hydrophilic and easy to make into pellets.
- Large scale and long-term feeding trial with hens, testing of Baltic mussel meal and algal biomass in a controlled environment for the whole life span of egg laying hens. To rule out that minute presence of pesticides and heavy metals bioaccumulate in the hen and reach higher/harmful levels in the eggs at the later part of the hen's life.

- The market of algal biomass as feed supplements is in its infancy and much research remain in down-stream processes such as optimal harvest and drying of algal biomass for highest quality output.
- Continue to raise awareness among customer and industry

## Referenser

- Adarme-Vega et al. 2012, Microbe Cell Factories, 11:96
- Berge & Austreng, 1998, Aquacult., 81, 79-90
- Briand & Morand 1997, J. Appl Phyc, 9:511-524
- Bryngelsson 2015, Chalmers Univ. of Technology, ISBN 978-91-7597-151-3
- EU directive 1986, 86/278/EEC amended 2009
- EC SWD 2014, 2014/167/EC
- Holman et al. 2012, J. Anim Physiol Anim Nutr 91:615-623
- Jain et al. 1991, Bioresour Technol, 41:273-277
- Kollberg & Ljungqvist 2005, Ekahaga Stift, dnr. 2005-48
- Leveille et al. 1960, Fitzsimons general hospital
- Lindahl 2013, Aquabest report, ISBN 978-952-303-056-5
- Livsmedelsverket, hanteringsrapport 2016  
Dioxin och dioxinlika PCB i ägg  
(<https://www.livsmedelsverket.se/globalassets/publikationsdatabas/rapporter/2016/hanteringsrapport-dioxin-och-dioxinlika-pcb-i-agg-2016.pdf>)
- OECD-FAO 2010
- Olofsson et al. 2015, Algal Res, 11:227-233
- Olofsson et al. 2012, Energies, 5:1577-1592
- Olofsson et al. 2019, Engineering in Life Sciences 19:330-340
- Rüdel et al. 2010, Environ Sci Pollut Res Int, 17:1025-1034
- Other projects:
- Baltic Blue Growth (<https://www.submarinetwork.eu/projects/balticbluegrowth>)
- ECOCHANGE  
(<http://www.umf.umu.se/english/ecochange>; <http://lnu.se/research-groups/marine-phytoplankton-ecology-and-applications/research/ecochange?l=en>)
- ALGOLAND ([www.lnu.se/algoland](http://www.lnu.se/algoland))

## **Del 3: Resultatförmedling**

### **Dissemination of results**

The result and status of the project has been communicated to the reference group, including stakeholders in the poultry industry and animal feed via workshops and newsletters. The project has been presented to various stakeholder group in society, e.g. to companies; to regional management; to junior and senior high school student in natural sciences; to the general public via several popular science events.

**ALGOLAND as an umbrella project was awarded the 2017 Sweden Impact Award by Aesis for conducting research with strong societal driving force in society and synergy effects.**

<b>Vetenskapliga publiceringar</b>	1) Olofsson M., Lindehoff E., Legrand C.(2019) Production stability and biomass quality in microalgal cultivation – contribution of community dynamics. <i>Engineering in Life Sciences 19:330-340</i>
	2) Mattsson M, Lindehoff E., Olofsson M, Legrand C. Boosting algal lipids- Diurnal shifts in temperature exceed the effects of nitrogen limitation <i>under review in Engineering Reports</i>
	3) Lindehoff E, Berglöf K, Mattsson L, Legrand C Nutrient recovery from blue mussel farming in the Baltic Sea <i>manuscript in prep</i>
	4) Elwing M., Lindehoff E., Legrand C Algae and blue mussel meal as protein source for poultry <i>manuscript in prep</i>
	5) Mattsson L., Lindehoff E., Legrand C et al. Nutrient recovery from leachate water <i>manuscript in prep</i>
	6) Sörensson E. et al. Bacterial and phytoplankton community composition affect the biomass production in large-scale algal cultivation systems <i>manuscript in prep</i>
	7) Nham Q et al. Using dairy waste eater for sustainable cultivation of microalgae, producing biomass for food and feed supplement <i>manuscript in prep</i>
	8) Mattsson L., Sörensson E., et al. Stability of microalgal populations promotes high quality products in large scale cultivation systems <i>manuscript in prep</i>
	9) Lindehoff E., Olofsson M, Mattsson L., Legrand C Long-term study of outdoor algal cultivation for CO2 capture and sustainable biomass production <i>manuscript in prep</i>
	10) Pohl E., Ma S., et al. Sustainability of microalgal solutions coupled to local industries <i>manuscript in prep</i>
	<b>Konferansbidrag</b>

<b>Övriga publiceringar</b>	Legrand, C. et al. European Algae Biomass (EAB); title: ” Harvesting CO2 from cement kiln flue gas using micro-algae: valuable biomass production in Sweden”, Berlin, Tyskland 20-21 april 2016				
	Legrand, C. et al. 1st Nordic Algae Symposium: title: “ALGOLAND-industry and ecology together”, Helsinki, Finland 31 januari 2018				
	Mattsson L., et al. Gordon research conference “Marine microbes” Title: Outdoor algal polyculture for CO <sub>2</sub> capture and sustainable biomass production, 01-06 juli 2018				
<b>Muntlig kommunikation</b>	<b>Typ av aktivitet</b>	<b>Syfte med aktivitet</b>	<b>Namn på aktivitet</b>	<b>Datum</b>	<b>Referens (tex. hemsida)</b>
	Föreläsning	Vetenskaplig presentation	Seminarie, SYKE, FI	16 mars, 2016	20 forskare, tjänstemän vid Finska Miljöcentralen
	Föreläsning , Nätverk	Vetenskaplig presentation	Kustbevakningens aspiranter, Karlskrona	31 mars, 2016	40 st aspiranter, blivande kustbevakare
	Föreläsning	Vetenskaplig presentation	Seminarie, Lnu	13 April, 2016	Statusuppdatering ALGOLAND, 25 studenter och forskare
	Föreläsning , Konferans	Vetenskaplig presentation	European Algae Biomass (EAB);	20-21 April 2016	Conference in Berlin, Germany
	Föreläsning , Nätverk	Populär-vetenskap, Vetenskaplig presentation	Kick-off ALGOLAND-FODER	13 April, 2016	Referens- och intressegruppsmöte, 30 personer
	Utställning, demo, föreläsning	Populär-vetenskap, information	Hållbarhetssafari- Ditt ekologiska fotavtryck 2016	31 aug 2016	400 gymnasieelever, Naturvetarklasser från, Kalmar och Kronobergslän
	Föreläsning Debatt	Populär-vetenskap, information	Hållbarhetssafari- Paneldebatt med Folke Rydén	31 aug 2016	300 personer
	Föreläsning , Nätverk	Populär-vetenskap, information	Möte Vattenråd	23 sep 2016	12 deltagare
	Föreläsning , Nätverk	Populär-vetenskap, Vetenskaplig presentation	Lina Mattsson presenterade och	5 okt 2016	Ca 30 forskare och studenter

			försvarade sin MSc avhandling		
Föreläsning, demo,	Populär-vetenskap, information	Falkenbergsskolan		7 okt 2016	25 elever, åk 7
Föreläsning, Nätverk	Populär-vetenskap, information	InnerWheel, årsmöte		10 okt 2106	50 deltagare
Föreläsning, Nätverk	Populär-vetenskap, information	Södermöreskolan		12 okt 2016	90 elever åk 8
Studiebesök Nätverk	Vetenskaplig presentation	AlgaeWays		13-14 okt 2016	Företag
Konferens, föreläsning nätverk	Vetenskaplig presentation	EnergiTing 2016		10 nov 2016	<a href="http://energikontorsydost.se/energiting-sydost-2016">http://energikontorsydost.se/energiting-sydost-2016</a>
Föreläsning, Nätverk	Vetenskaplig presentation	Miljörisikanalysprogrammet, Miljökemi		27 Feb, 2017	Distanskurs med 20 studenter
Utställning, demo, Nätverk	Populär-vetenskap, information	Baltic Sea Future, Stockholmsmässan		6-7 mar, 2017	<a href="http://www.balticseafuture.org/">http://www.balticseafuture.org/</a>
Föreläsning, Nätverkskandidate	Vetenskaplig presentation	Seminarie, Ekologi inst. Lunds universitet		22 mars, 2017	30 forskare och lärare inom biologi och miljövetenskap
Studiebesök Nätverk	Populärvetenskap, information	CleanTech International		28 mar 2017	Internationellt projekt, 4 deltagare
Intervju	Populärvetenskap, information	Reportage om CCU för Quartz		26 apr 2017	Journalist Akshat Rathi, Quartz, <a href="https://qz.com/">https://qz.com/</a>
Föreläsning, Nätverk	Populärvetenskap, information	Linnaeus Technical Centre (LTC) och Linnaeus Innovation Design Lab (Lidlab)		8 maj 2017	10 deltagare
Föreläsning, studiebesök	Populärvetenskap, information	Hållbarhetssafari, - Ditt ekologiska fotavtryck 2017		30 augusti 2017	400 studenter

	Poster- presentation	Conference, network,	GENECO summer meeting	31 augusti 2017	PhD nätverk, 30 deltagare
	Föreläsning , Nätverk	Populär-vetenskap, Vetenskaplig presentation	Shenhong Ma presenterade och försvarade sin MSc avhandling	1 sept 2017	Ca 30 forskare och studenter
	Föreläsning , Nätverk	Populär-vetenskap, Vetenskaplig presentation	Kimberly Berglöf presenterade och försvarade sin MSc avhandling	1 sept 2017	Ca 30 forskare och studenter
	Föreläsning , Nätverk	Conference, network, Populärvetenskap, information	ALGOLANDs kustmiljöturné	8 sept 2017	30 deltagare; collaborative workshop with representatives from industry, academia, local government
	Föreläsning	Vetenskaplig presentation	EEMiS seminar series, Lnu	05 dec 2017	Ca 30 forskare och studenter
	Föreläsning , Nätverk	Conference, Vetenskaplig presentation	1 <sup>st</sup> Nordic Algae Symposium, Helsinki	31 january 2018	<a href="https://www.nordforsk.org/en/events/nordic-algae-symposium-2018-nas18">https://www.nordforsk.org/ en/events/nordic-algae- symposium-2018-nas18</a>
	Föreläsning , Nätverk	Network, Populärvetenskap, information	Workshop för Storskalig gödselhantering och projektet RISE	21 mars 2018	
	Föreläsning , Nätverk	Conference, network, Populärvetenskap, information	Algoland 2030 Workshop	24 april 2018	22 deltagare; collaborative workshop with representatives from industry, academia, local government
	Studiebesök, demo, föreläsning	Populärvetenskap, information	Naturvetarklasser från Markaryds kunskapscentrum	9 maj 2018	Ca 50 gymnasieelever

	Föreläsning , Nätverk	Conference, Vetenskaplig presentation	Stockholm Diplomat Corps visit to Linnaeus University	15 May 2018	Stockholm Diplomat Corps visit to Linnaeus University
	Föreläsning , Nätverk	Conference, Vetenskaplig presentation	KSRR Styrelse	25 may 2018	25 personer
	Föreläsning , Nätverk	Conference, Vetenskaplig presentation	Kalmar Energi anställda på Moskogen kraftvärmeverk	11 juni 2018	15 personer
	Conference , network,	Conference, network, EEMiS	Ledarskapskonferens	20 June 2018	Kalmar, Calmare Stadshotell
	Poster- presentation	Conference, network,	Gordon research seminar "Marine microbes"	29 june 2018	Forskarseminarium, 50 deltagare
	Science outreach presentation	Vetenskaplig presentation	Visit to Linnaeus University – Kalmar Sjöfartshögskolan captains from 1960	8 June 2018	Calmare Nyckel training vessel + KSL
	Poster- presentation	Conference, network,	Gordon research conference "Marine microbes"	5 juli 2018	Forskarseminarium, 50 deltagare
	Föreläsning , studiebesök	Populärvetenskap, information	Hållbarhetssafari, - Ditt ekologiska fotavtryck 2018	29 augusti 2018	200 deltagande gymnasieelever och lärare
	Poster- presentation	Conference, network,	GENECO summer meeting	5 sept 2018	PhD nätverk, 30 deltagare
	Föreläsning	Network, Populärvetenskap, information	Rådgivarträff, Greppa Närningen, Lst Kalmar län	30 aug 2018	20 deltagare från lst, kommun
	Föreläsning	Network, Populärvetenskap, information	Kurs, Greppa Närningen, Lst Kalmar län	11 okt 2018	30 deltagare från lst, kommun



	Populärvetenskaplig föreläsning	Populärvetenskap, information	Vimmerby folkhögskola	12 dec 2018	150 deltagande elever och seniorer
	Föreläsning	Vetenskaplig presentation	EEMiS seminar series, Lnu	18 dec 2018	Ca 30 forskare och studenter
<b>Studentarbete</b>	<b>Master of Science Thesis</b>				
	Hirwa, M. (2016). Effect of microalgal harvesting methods on the biomass quality, Lnu				
	Shenhong, M. (2017). Life-cycle assessment and life-cycle cost analysis of microalgal biomass production using innovative and traditional, Lnu				
	Berglöf, K. (2017). Optimal harvest time of farmed <i>Mytilus edulis</i> in southwestern Baltic Sea, Lnu				
	Nham, Q. (2019) Using dairy waste eater for sustainable cultivation of microalgae, producing biomass for food and feed supplement, Lnu				
<b>Övrigt</b>	Awards				
	Solrospris 2016, Climate Commission, Kalmar County <a href="http://www.lansstyrelsen.se/Kalmar/sv/nyheter/2016/Pages/solrospriset-2016.aspx">http://www.lansstyrelsen.se/Kalmar/sv/nyheter/2016/Pages/solrospriset-2016.aspx</a>				
	Sweden Science Impact Award in Medical and Life Sciences 2017 <a href="http://aesisnet.com/event/sweden-impact-award-2017/">http://aesisnet.com/event/sweden-impact-award-2017/</a>				