Use of microalgae in salmon diets

M. Sørensen. K. Viswanath

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mette.sorensen@nord.no

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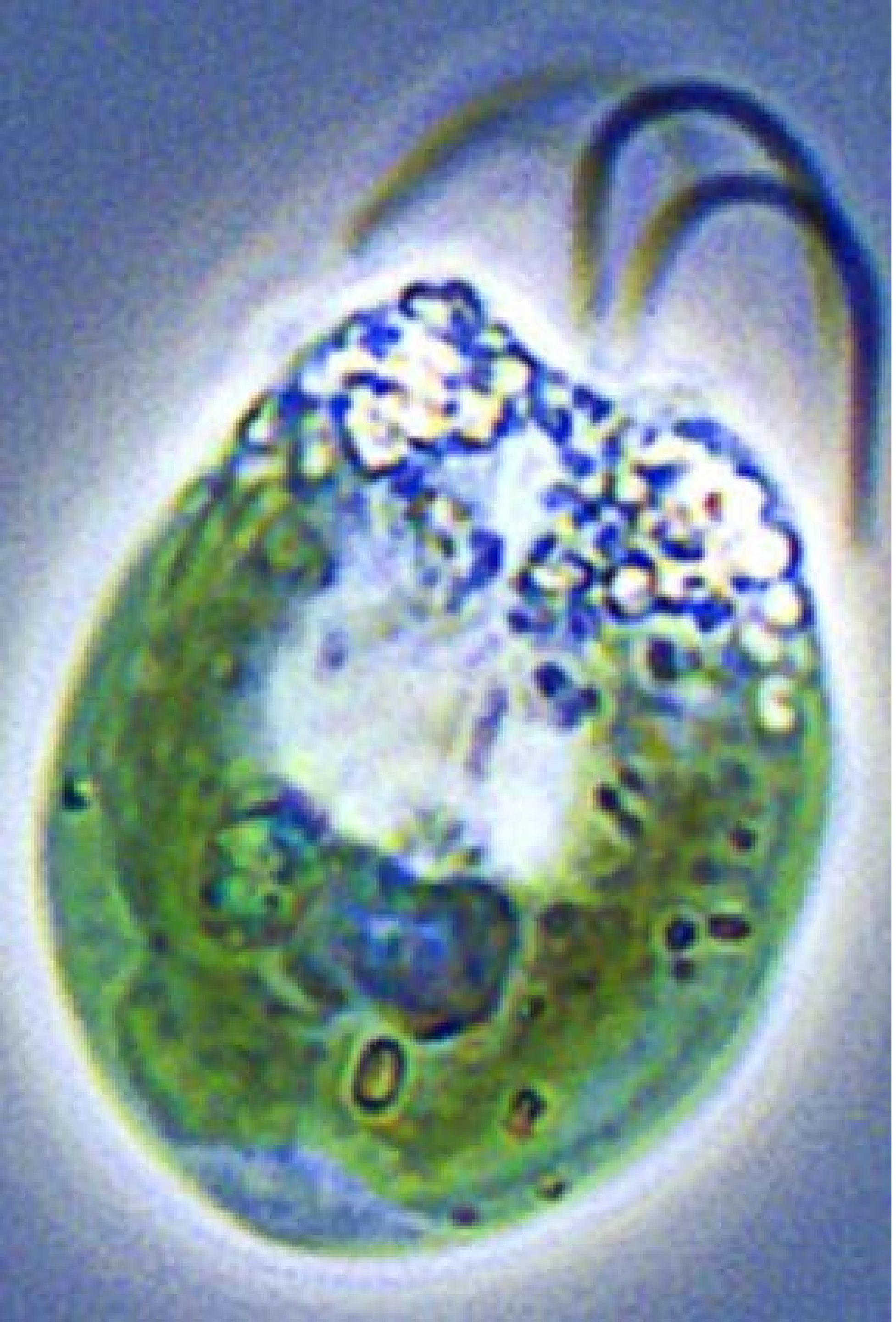
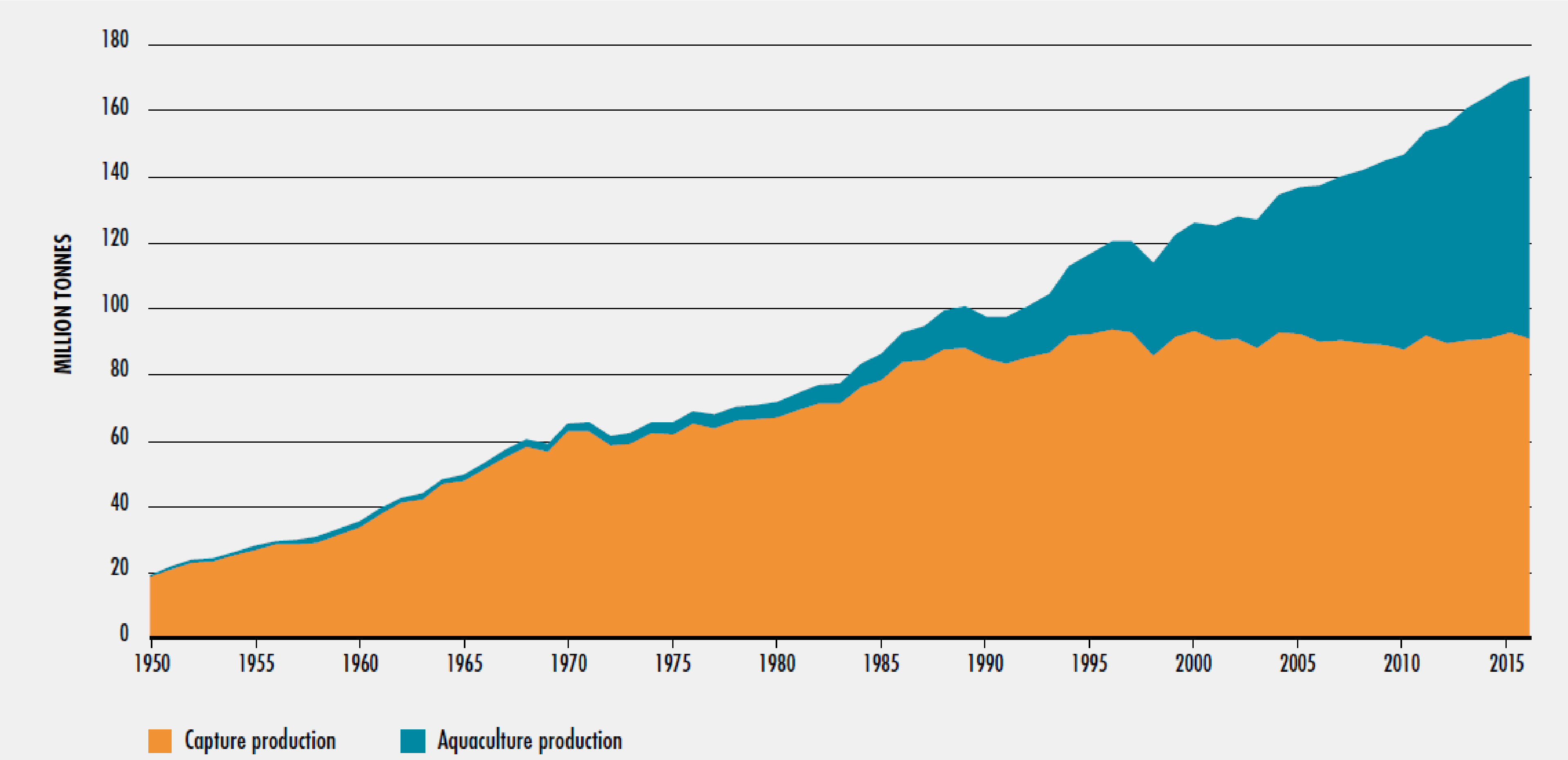


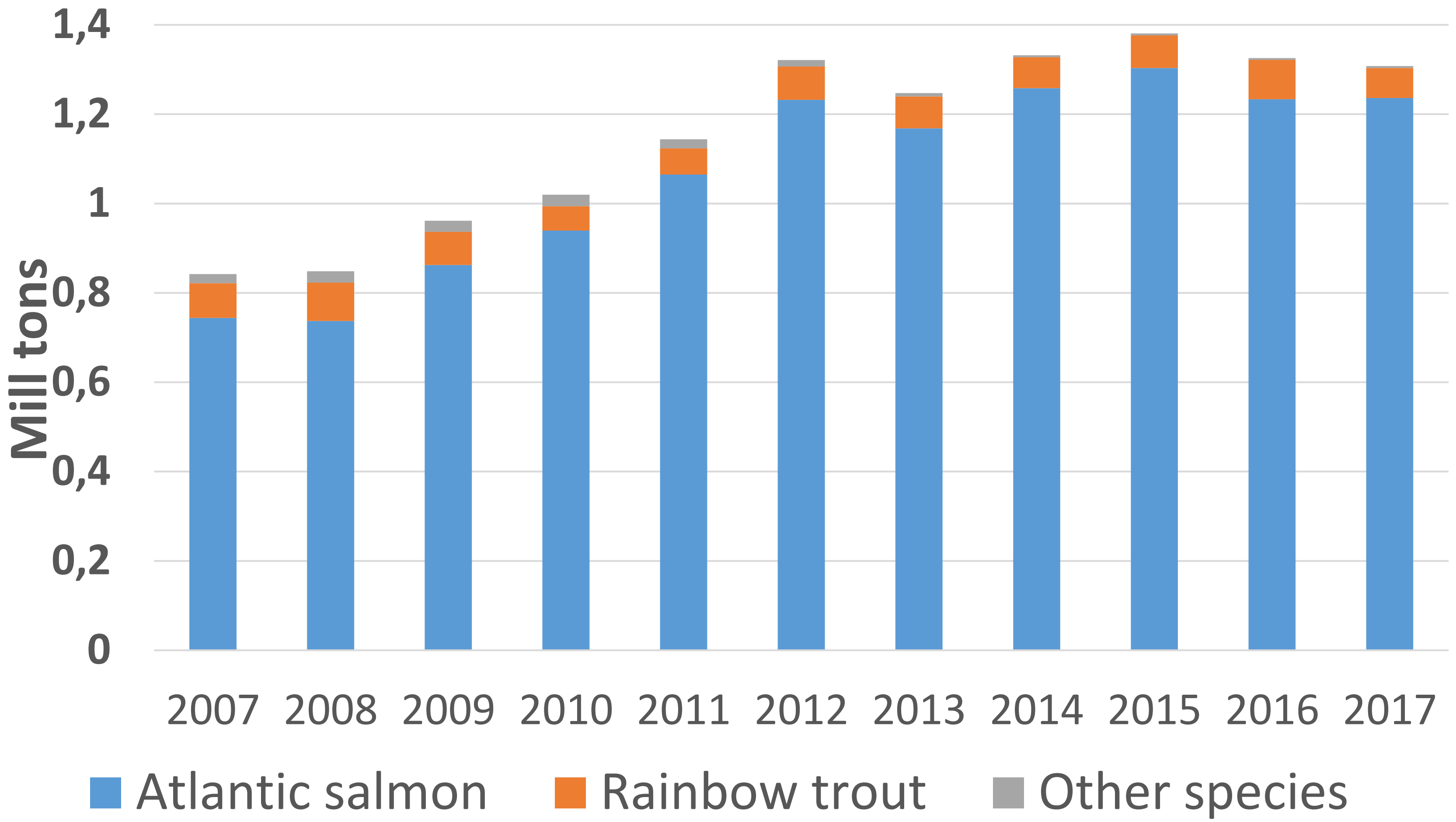
Content of the presentation

- Background for the commercial interest in microalgae
- Challenges related to (nutritional) quality issues
- How do we try to resolve these issues?
- How far are the new protein from the market?

World fish production from wild fisheries and Aquaculutre (FAO, 2018)



Aquaculture production in Norway



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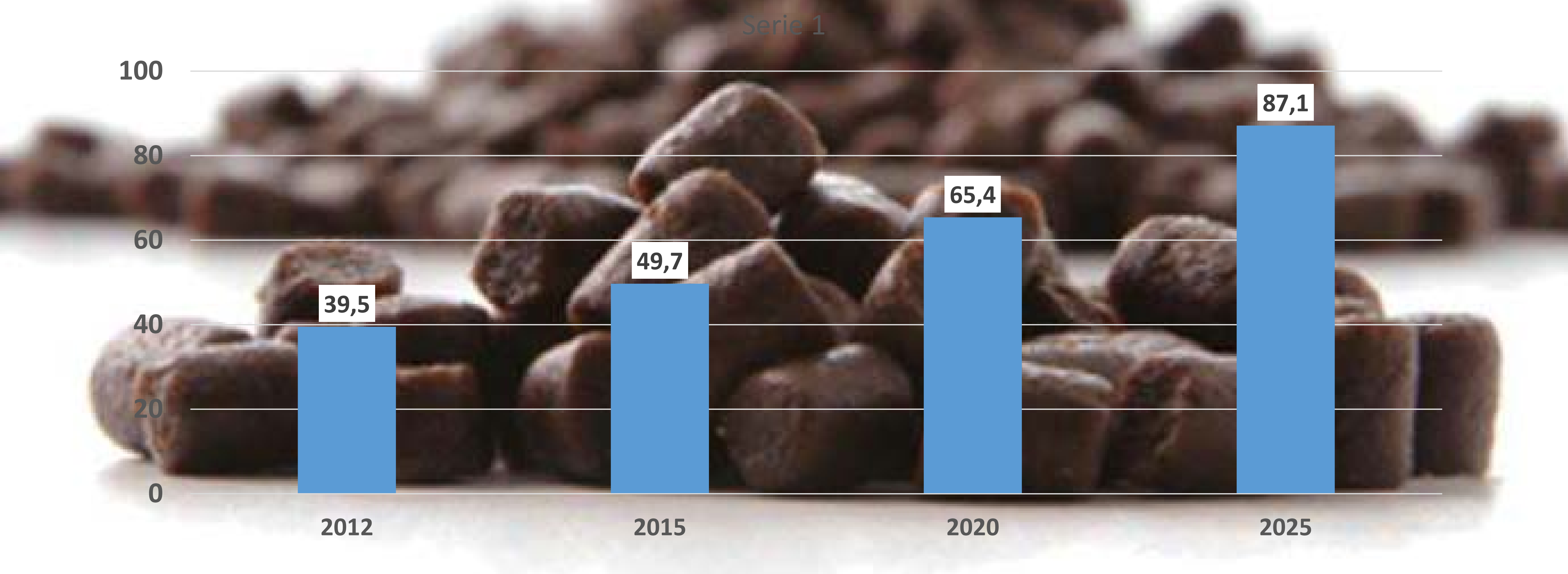
Estimated future growth of commercial aquafeed production (MMT)



Norwegian salmon farmers used 1.64 MMT of feed in 2017

Tacon and Metian. 2015

Microalgae is sustainable alternatives

SCIENTIFIC REPORTS

OPEN

Marine microalgae commercial production improves sustainability of global fisheries and aquaculture

Colin M. Beal[1,2], Léda N. Gerber[2], Supis Thongrod[3], Wutiporn Phromkunthong[4], Viswanath Kiron[5], Joe Granados[2], Ian Archibald[2,6], Charles H. Greene[2,7] & Mark E. Huntley[2,8]

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Microalgae will become important

- PwC Seafood Barometer 2017
- Sustainable growth towards 2050
- Algae most important ingredient in salmon feed in the future

The government has a vision of Norway becoming the world's leading seafood nation

Verdiskapning basert på produktive hav i 2050

In 2012, notable scientists, researchers and opinion leaders published a report called "value creation based on productive oceans in 2050". They have estimated that it is possible to have a six-fold increase in sales value of Norwegian marine production, by 2050. This requires, among other things, **a production of salmon and trout of 5 million tonnes – almost a five-fold from today's level.**[1]

Verdens fremste sjømatnasjon

In 2013, the Norwegian Ministry of Fisheries and Coastal Affairs released parliament report no. 22 (Meld. St. 22),where the government's vision for Norway, as a seafood nation, is detailed. **The government wants Norway to be the world's leading seafood nation**, and adopts the view and vision that seafood production can be increased six-fold by 2050.[2]

Havbruksmeldingen

In 2014, the Norwegian Ministry of Fisheries and Coastal Affairs published parliament report no. 16 (Meld. St. 16), presenting their view on how vision 2050 can be reached. Global demand for salmon increases, but production growth has stagnated due to sustainability challenges. Historically, regulations and policies for growth, and changing governments, have shown nothing but predictability. The allocation of new licenses has been termed a "beauty contest" by the press. **The government, therefore, suggested a predictable system for sustainable growth based on environmental indicators.** This framework has been named «The Traffic Light System», where Norway is divided into 13 production areas and gives each area a green, yellow or red light. The new system came into effect in October 2017.[3]

55.6% *of leaders in the industry* ***believe algae will be the most important ingredient*** *in salmon feed in the future.*

PwC's Point of View:

After solving the short term issues regarding lice and lice treatment, the next big challenge to overcome is where and how to find sustainable feed ingredients with the right nutritional content for salmon.

We believe that the salmon feed in 2050 will still have a high share of plant based ingredients, but with a significant share of algae and a small share of by-products. The share of traditional fish oil and meal will continue to fall.

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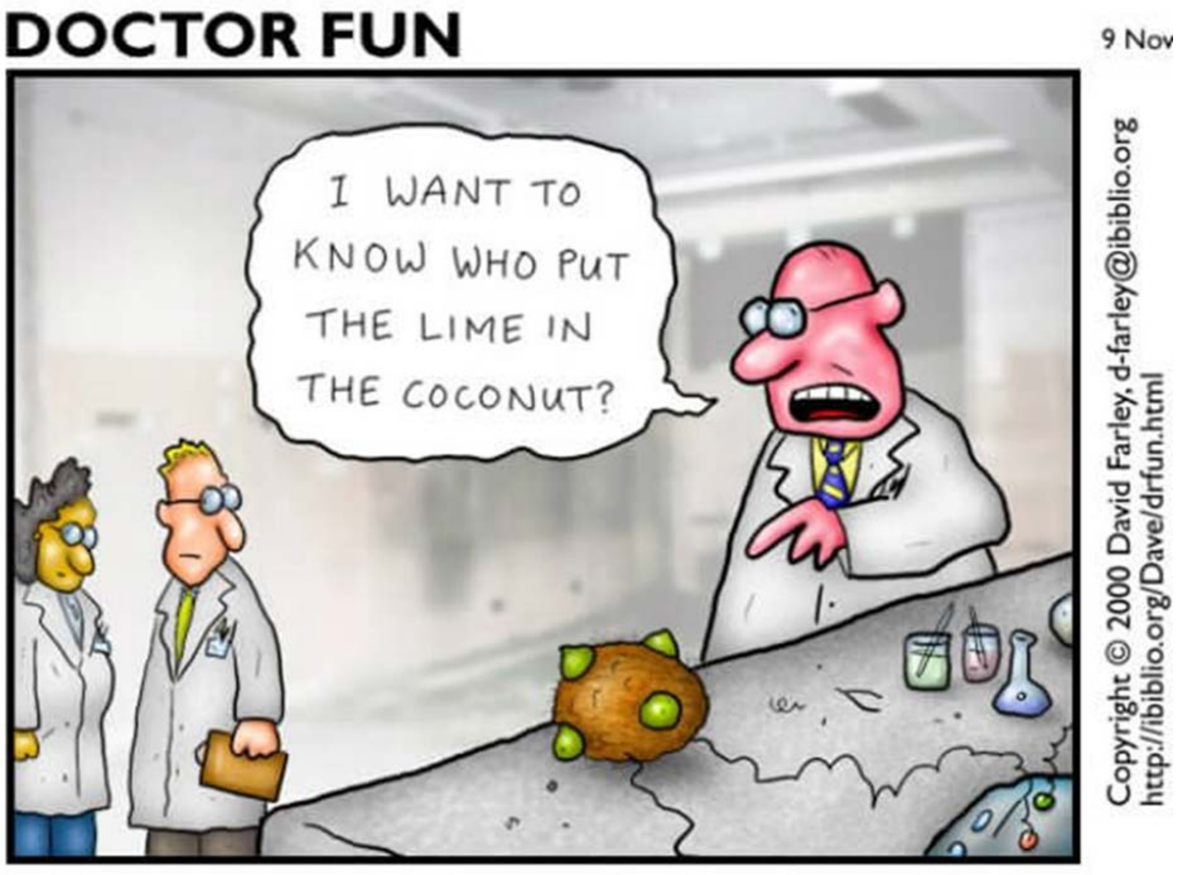
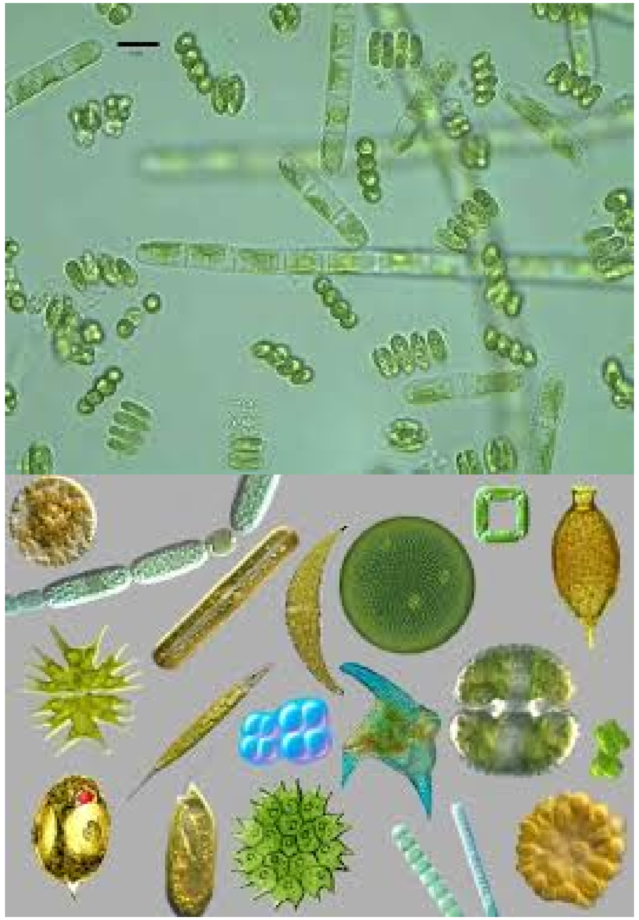
Fish oil alternatives:



Yet another unauthorized experiment in genetically-modified food



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Microalgae research at Nord University

US Funding

2009-2011: Defatted microalgae from biorefinery as aquafeeds

2012-2015: Large-Scale Production of Fuels & Feed from Marine Microalgae
2017-2020: Marine Algae Industrialisation Consortium

EU/Norwegian funding

2014-2018: Bioteknologi
- en framtidsrettet næring

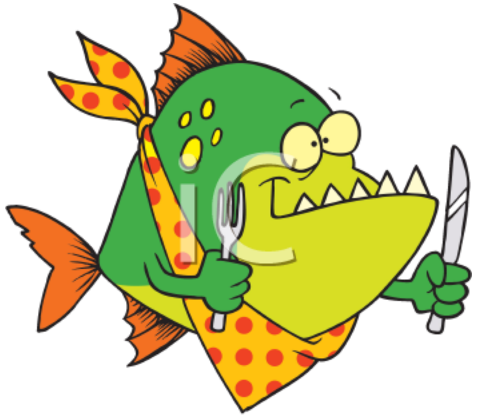
2016-2020: Alger4laks

2017-2021: Algae to Future

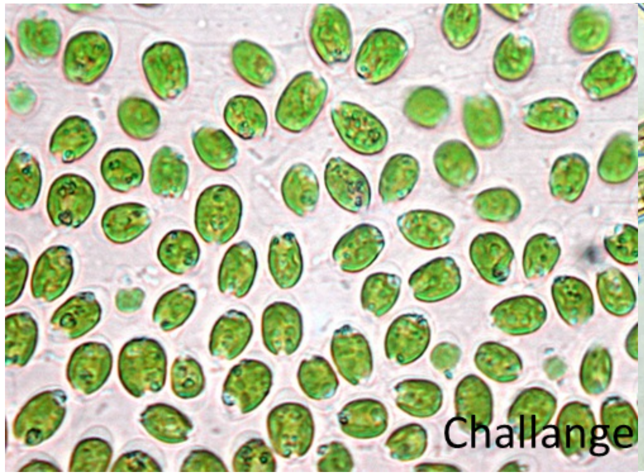
2017-2020: Metabolism of novel strain of Arctic algae

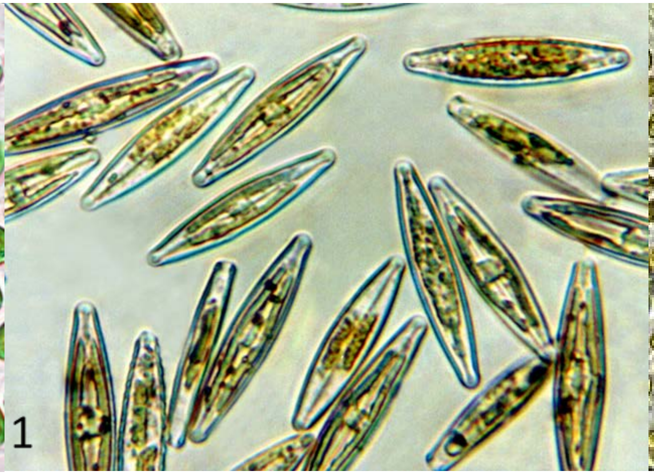
At Nord University we perform research to investigate the potential of different microalgae – both whole cells as well as defatted biomass as fish meal replacer in diets for Atlantic salmon

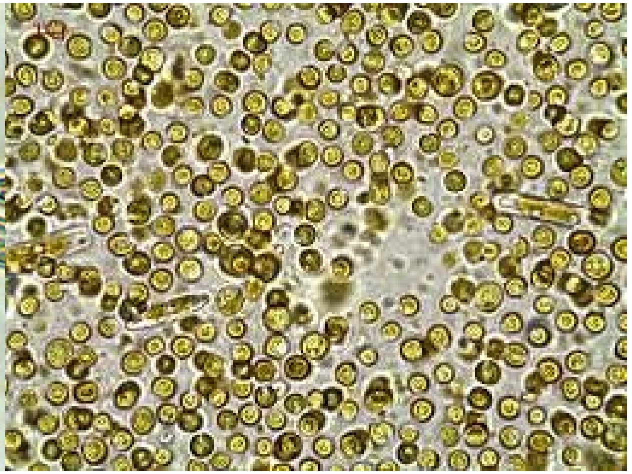
Challenge 1: Chemical composition vary among microalgae



The most abundant microalgae divisions: Chlorophyta (green algae), Bacillariophyta (diatoms), and Chrysophyta (golden algae).







Chlorella sp.

Tetraselmis sp.

Phaeodactylum tricornutum

Chaetoceros sp.

Thalassiosira pseudonana

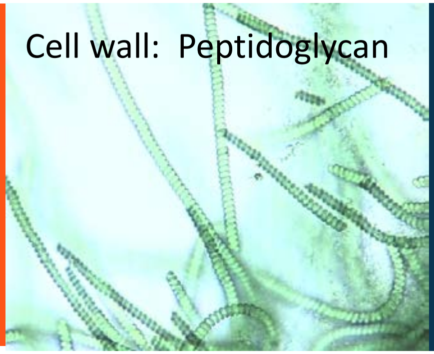
Isochrysis sp.

- **Storage polysaccharide: Starch**
- **Cell wall: Cellulose**

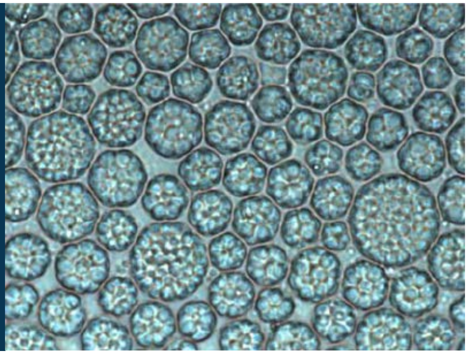
Storage compound: Lipids
Cell wall: Silica

- **Storage polysaccharide: Chrysolaminarin**
- **Cellulose, calcium carbonate**

The photosynthetic bacteria is referred to as ‘microalgae’ (blue-green algae: *Spirulina*).



The marine fungus-like *Schizochytrium* is also referred to as heterotrophic ‘microalgae’.



Microalgae can be
good sources of protein and lipids

Protein: >60% (e.g. *Chlorella*, *Spirulina*)
Lipid: >50% (e.g. *Nannochloropsis*, *Schizochytrium*)

Microalgae also contain functional or bioactive components that have potential to provide an additional health benefit in aquafeeds

Microalgae	Moisture	Protein	Lipid	References
Nannochloropsis oceanica	5.1	45.3	8	Skrede et al. (2011)
Nannochloropsis	9.1	29	51.3	Ju et al. (2009)
Nannochloropsis gaditana	3	52.5	15.5	Teuling et al. (2017)
Phaeodactylum tricornutum	3	47.5	7.2	Skrede et al. (2011)
Isochrysis galbana	11.2	17.8	14.4	Skrede et al. (2011)
Nannochloropsis + Isochrysis	9.2	42.1	18.2	Walker and Berlinsky (2011)
Scenedesmus dimorphus	5.1	40.7	8.1	Teuling et al. (2017)
Nanofrustulum sp. (defatted)	3.15	11.9	3.1	Kiron et al. (2012)
Thalassiosira weissflogii	15.2	18.3	12.9	Ju et al. (2009)
Tetraselmis sp.	10.8	27.9	3.8	Kiron et al. (2012)
Tetraselmis suecica	5.9	45.8	7.5	Cardinaletti et al. (2018)
Tisochrysis lutea	10	41.7	23.4	Cardinaletti et al. (2018)
Spirulina sp.*	17.8	61.3	5.5	Sarker et al. (2016)
Spirulina sp.*	9.9	53.5	2.6	Safari et al. (2016)
*Arthrospira maxima**	9.6	72	5.6	Teuling et al. (2017)
Chlorella vulgaris	5.9	63.5	10.3	Teuling et al. (2017)
Chlorella sp.	5	54.5	9.4	Sarker et al. (2016)
Chlorella sp.	7.4	47.4	7	Shi et al. (2017)
Schizochytrium sp.*	3.5	11.9	54.1	Sarker et al. (2016)
Schizochytrium sp.*	1.6	13.2	61.4	Kousoulaki et al. (2016)
Haematococcus pluvialis	-	10	42	Barros et al. (2012)

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Chemical composition (in DM) for some microalgae (own research)

Ingredient	Protein, %	Lipid, %	Carbohydrates, %	ash, %	Gross energy, Mj/g
Fish meal	70	9.7	-	14.7	20.1
Whole cell					
Scenedesmus sp.	45.7	9.1	15.6	8.3	14.9
Tetraselmis	23.7	6.4	17.4	33.1	n.a.
Nannochlorpsis	37.7	14.7	9.7	23.5	n.a
Phaeodactylum tricornutum	49.0	7.37	24.8	15.8	n.a
Defatted biomass					
Nannochlorpsis sp.	43.1	2.6	n.a	23.5	19.0
Desmodesmus sp.	30.4	1.1	n.a	18.0	18.7

Amino acid composition of some microalgae

g/100 g protein	Fishmeal	Isochrysis	Nanofrustulum	Nanno-chloropsis	Phaed-actylum	Scene-desmus	Tetrea-selmis	Schizo-chytrium
Arg	3.7	**2-6**	**6**	**2-8**	**6**	**6-7**	**6-9**	**1-12**
His	1.4	**1-3**	**1**	**1-3**	**2**	**2**	**1-2**	**1-3**
IsoL	2.5	1-5	4	1-6	5	4-5	3-4	1-3
Leu	4.5	**3-9**	**7**	**5-11**	**7**	**9**	**7**	**1-6**
Lys	4.7	2-6	7	3-8	6	5-6	6-7	1-4
Met	1.8	**1-3**	**2**	**1-3**	**3**	**2**	**2**	**1-10**
Phe	2.4	2-6	4	2-6	5	5-7	5	1-3
Thr	2.5	**2-5**	**5**	**4-6**	**5**	**6**	**4-5**	**1-3**
Tryp	0.7	**1-3**	**1**	**1-4**	**3**	**1-2**	**1-2**	**1-2**
VAl	2.7	2-6	5	3-7	5	6	5	1-5

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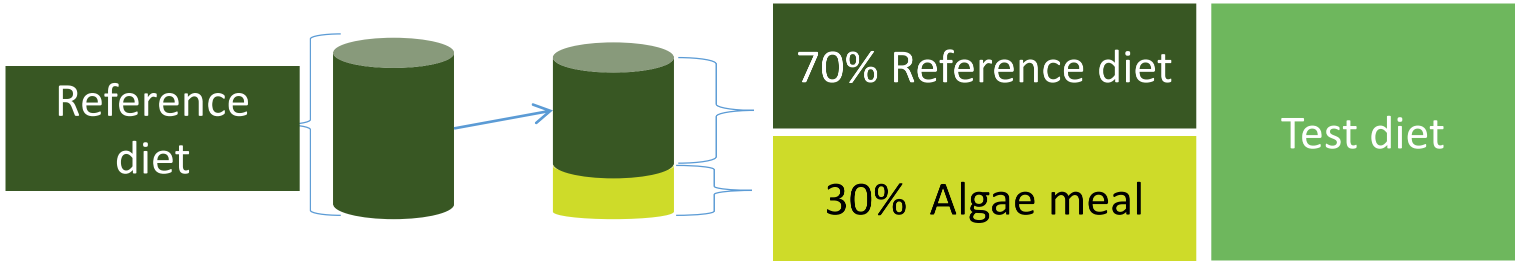
Potential of defatted biomass of *Nannochlorpsis* sp. and *Desmodesmus* Sp.

Investigate effects of different inclusion level on

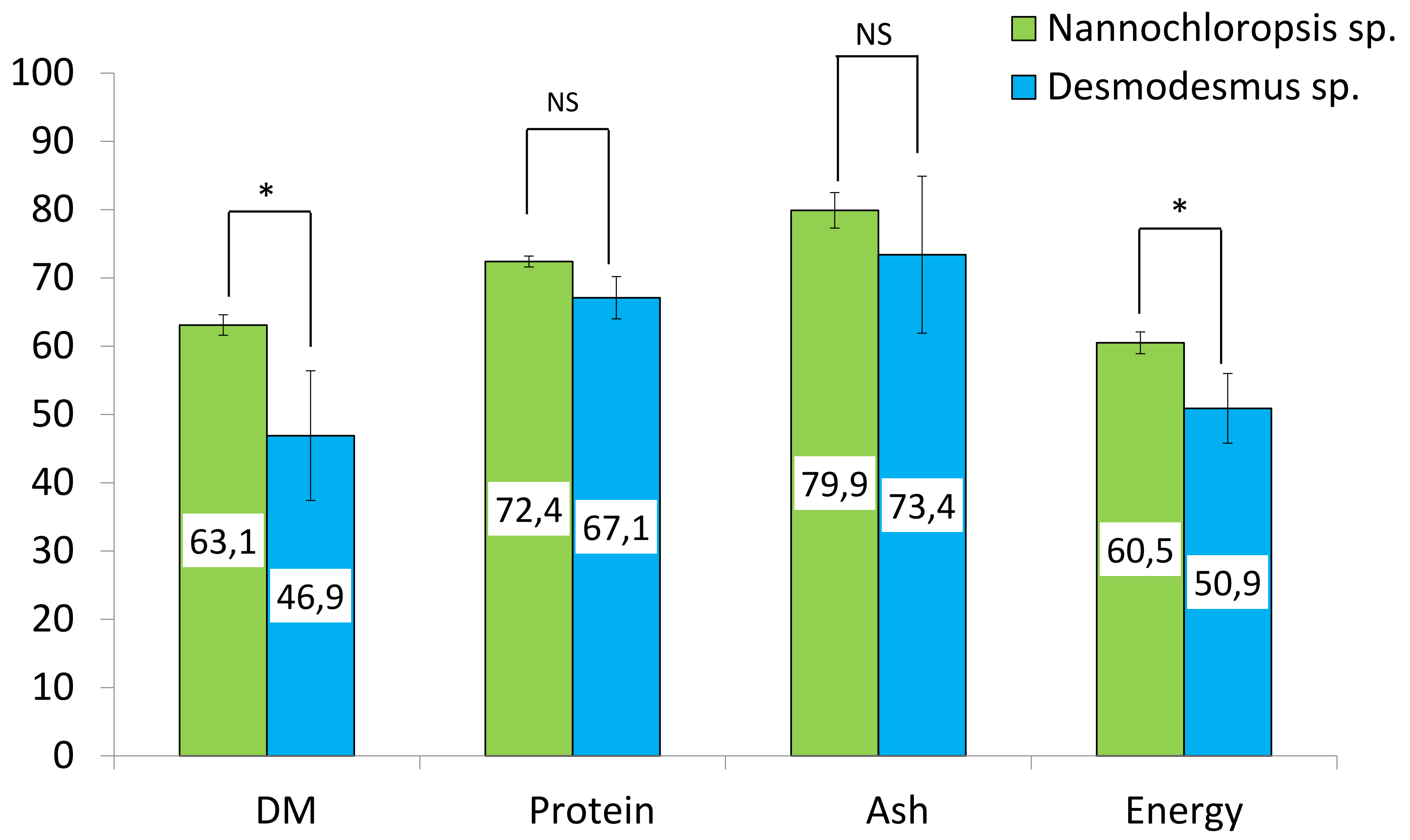
- Digestibility of biomass
- Growth performance
- Digestibility of feeds
- Health and welfare

Principles for formulation of experimental diets to calculate ingredient digestibilities

- The reference diet (basal diet) was a fish meal-based diet formulated to meet or exceed nutritional requirements of Atlantic salmon (NRC 2011).



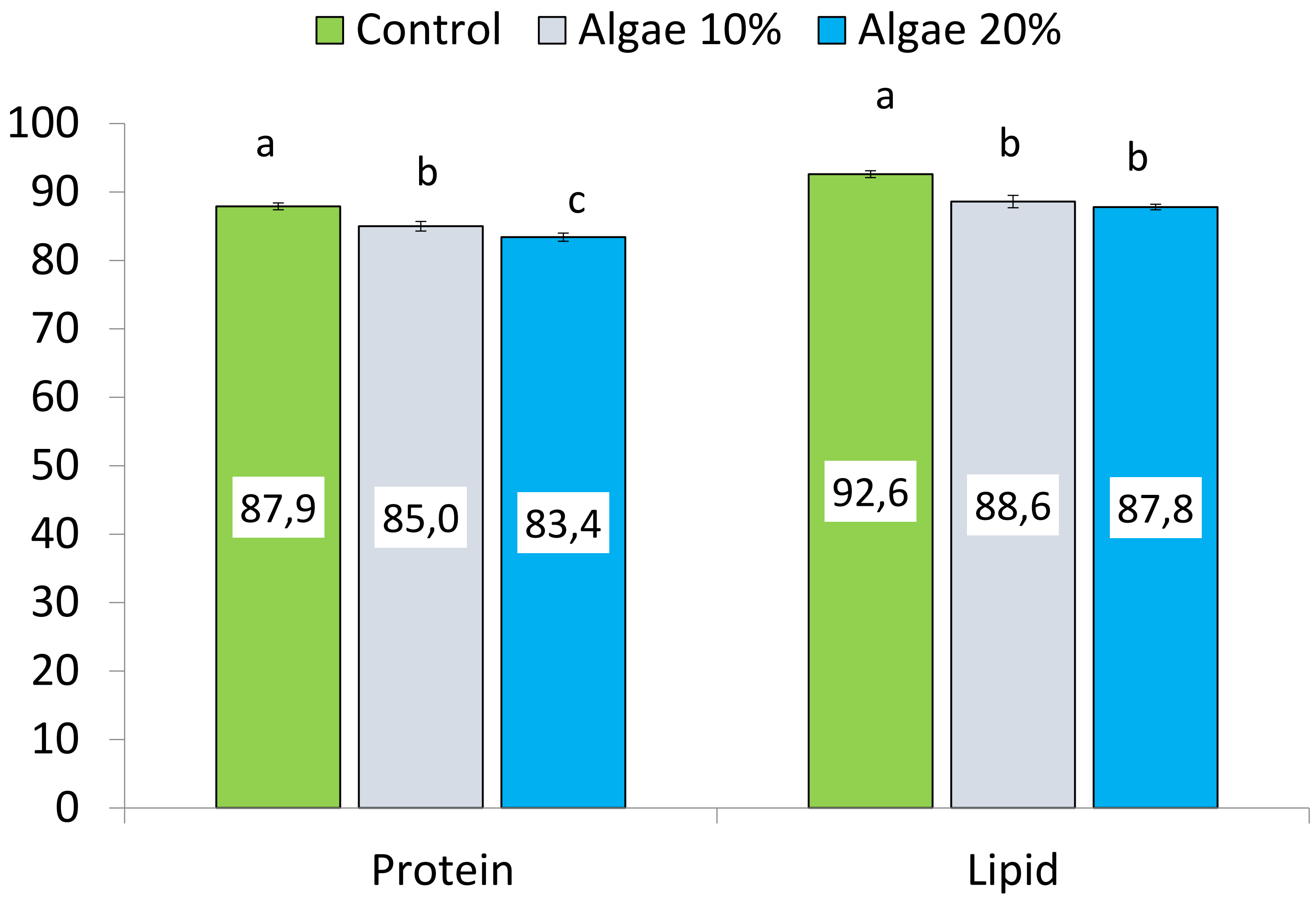
Digestibility of defatted microalgae



Note: * means significant differences (P < 0.05), NS means no significant differences

Results are published in Gong et al., 2018. Aquacult. Nutr.

Apparent digestibility of feeds with Nannochlorpsis sp.



Results are published in Sørensen et al., 2017 PLOS ONE

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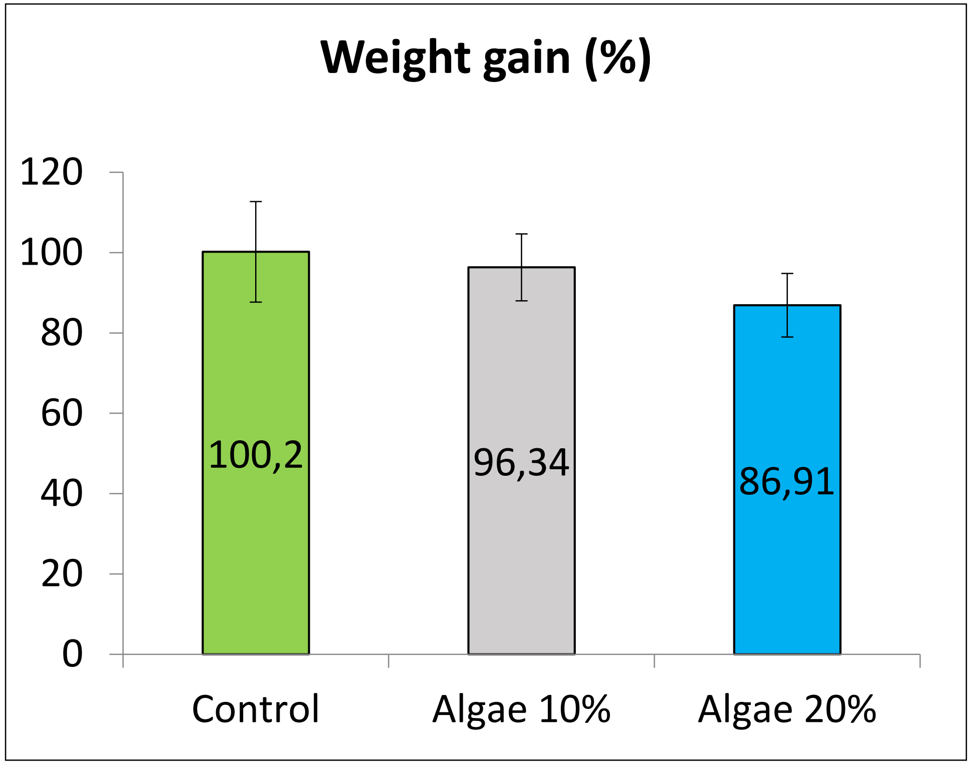
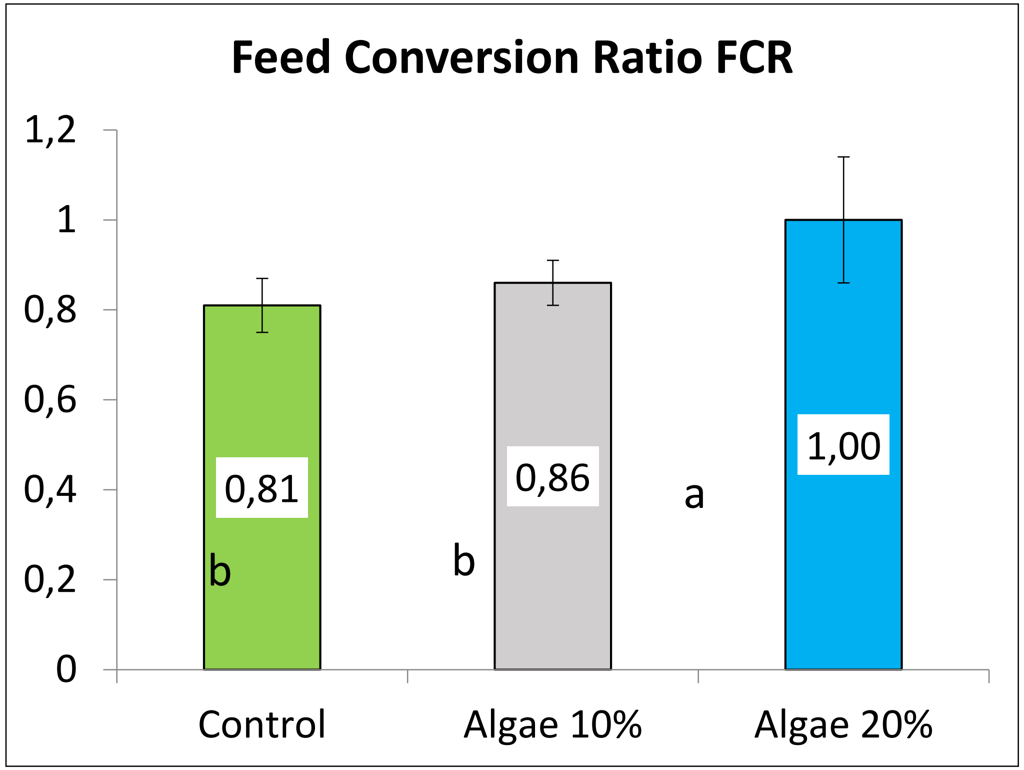
Growth performance replacing fish meal with Nannochloropsis (defatted)





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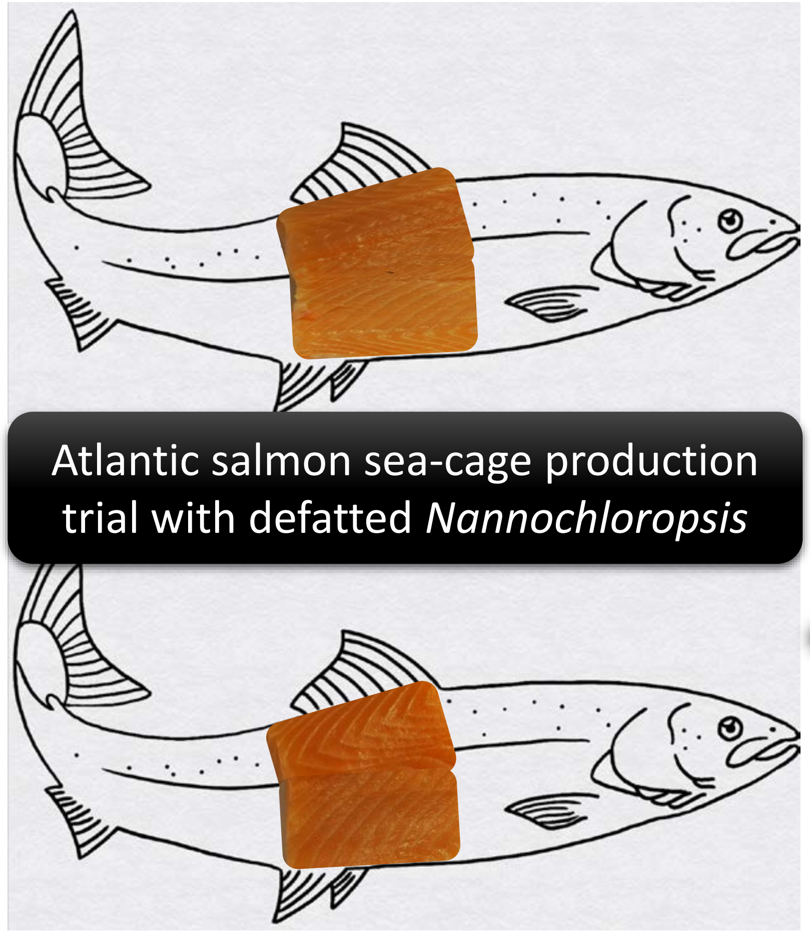
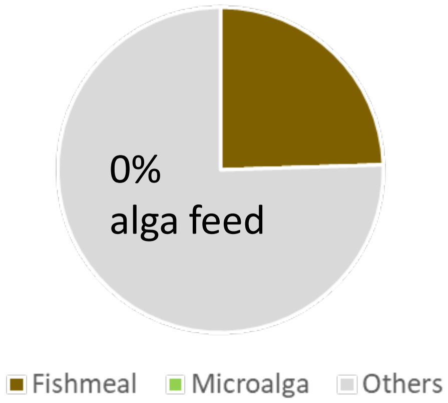
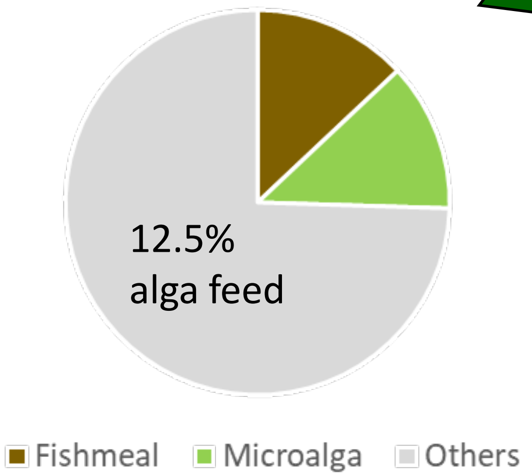
Nannocloropsis in fish feed has a positive effect on pigmentation







- *Nannochloropsis-in feed*:
- Same growth;
- Increased pigmentation

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The potential of *Scenedesmus* sp. to supply both protein and lipid in the diet

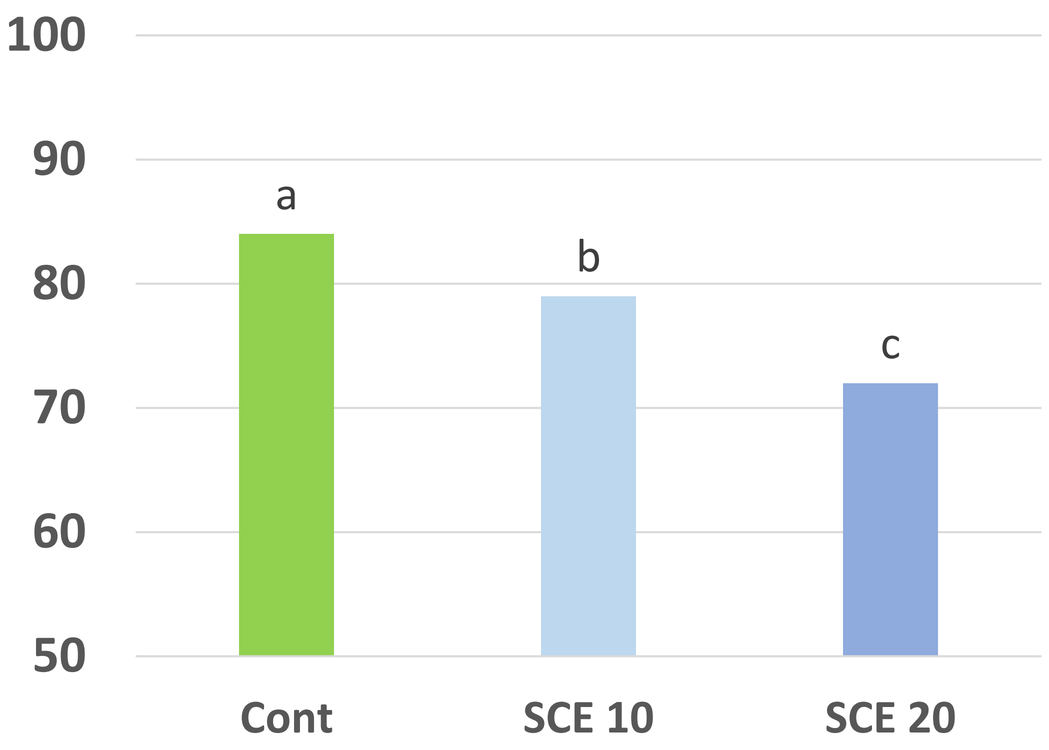
	Cont	SCE 10	SCE 20
Fishmeal	10.00	5.00	2.50
Scenedesmus sp.	**0.00**	**10.00**	**20.00**
Protein mix	51.50	50.40	46.75
Wheat meal	14.50	11.00	7.65
Fish oil	10.00	9.80	9.55
Rapeseed oil	10.00	9.80	9.55
Vitamin & Mineral Premix	1.00	1.00	1.00
Amino acids + additives	3.98	3.98	3.98
Yttrium oxide	0.02	0.02	0.02

Protein mix: Soy protein concentrate, pea protein concentrate, potato protein concentrate, wheat gluten, corn gluten

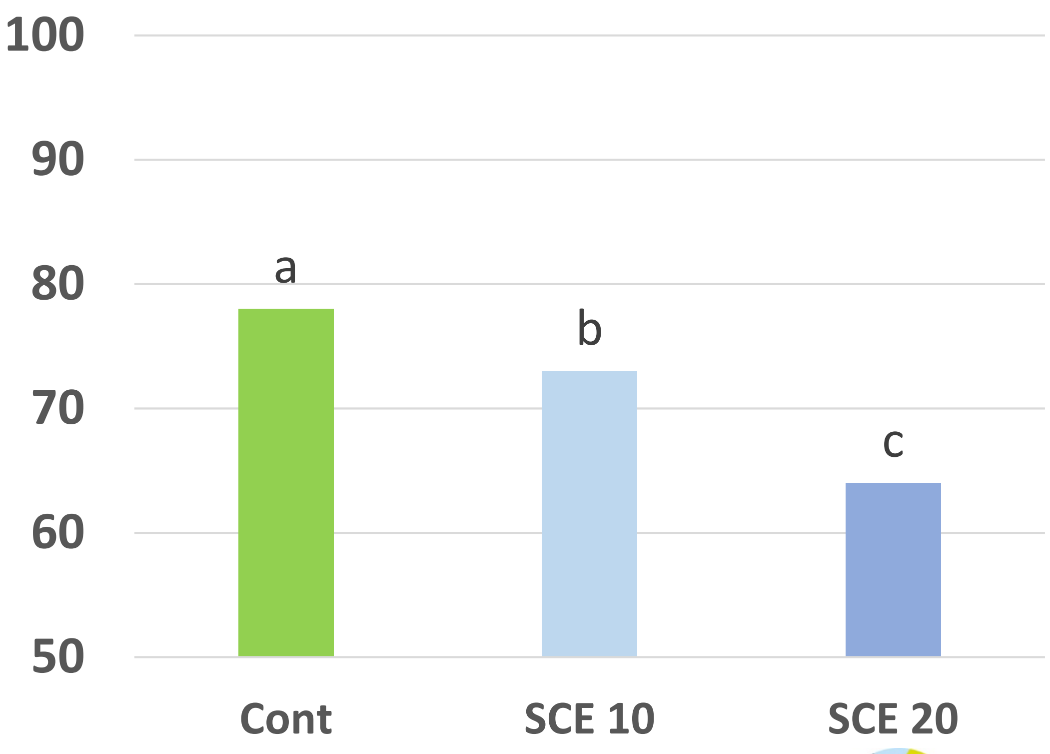
Gong et al., 2019

Protein and energy digestibility

Protein. %



Energy. %



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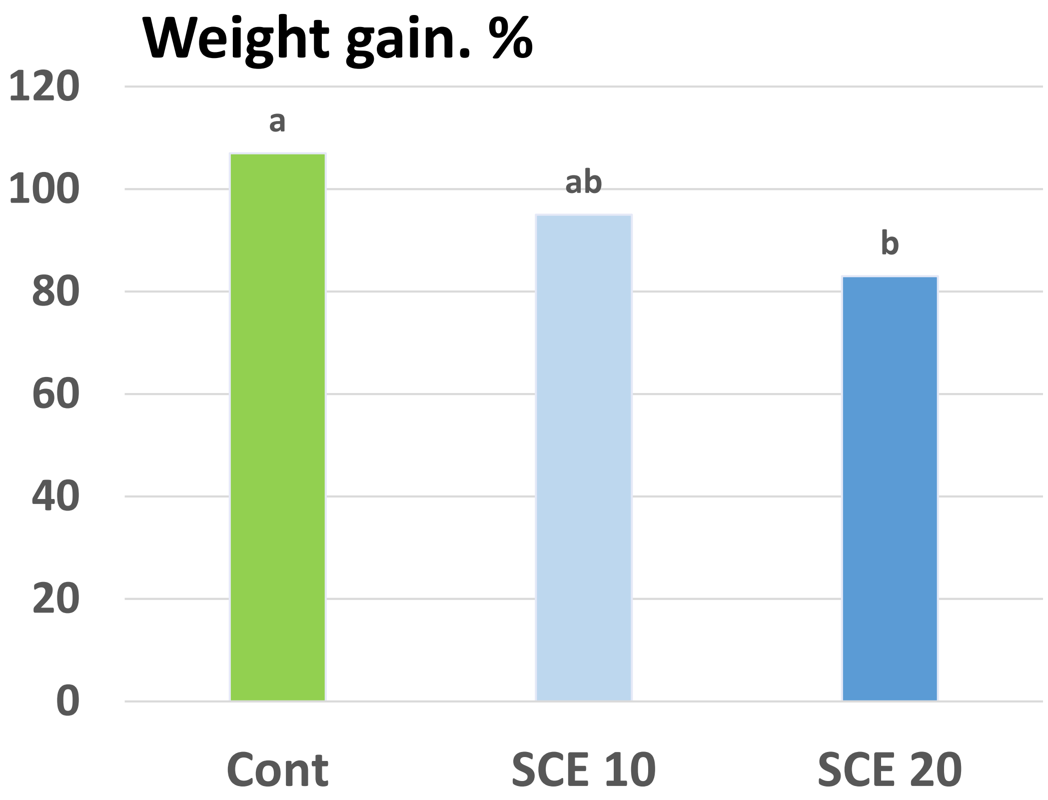
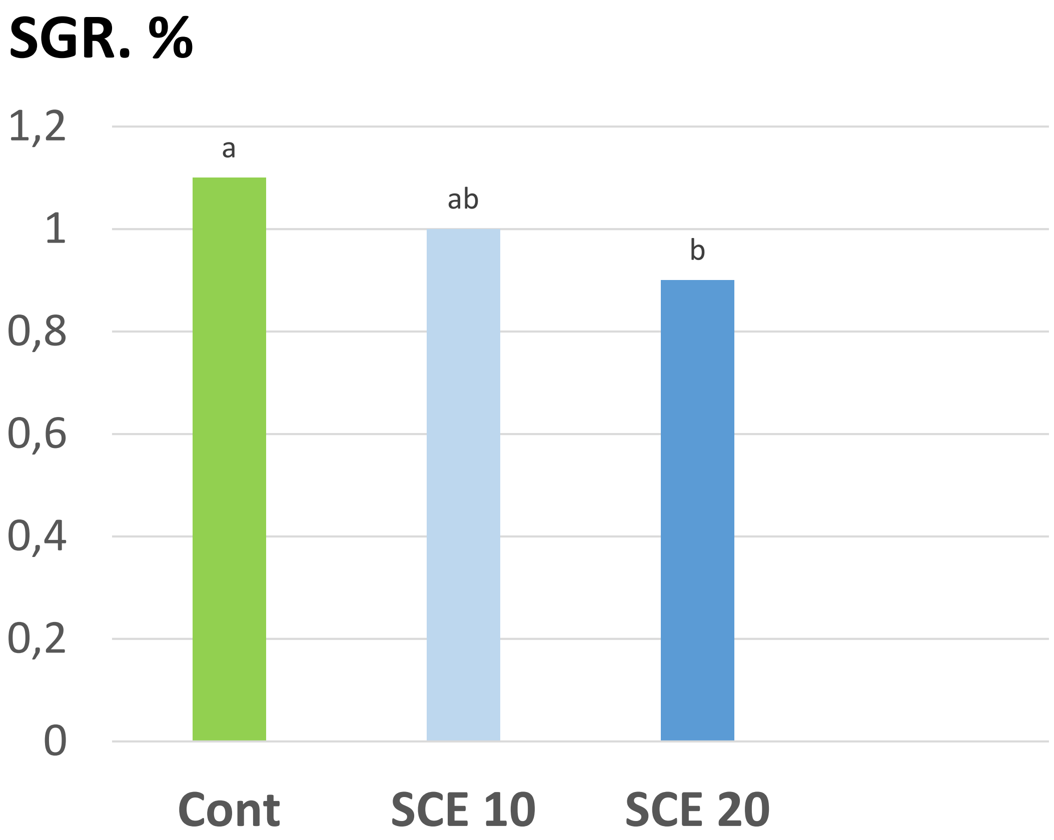
Results



Weight gain. %
120
100
80
60
40
20
0
a
ab
b
Cont
SCE 10
SCE 20



SGR. %
1,2
1
0,8
0,6
0,4
0,2
0
a
ab
b
Cont
SCE 10
SCE 20

Whole body fatty acid composition

	Cont	SCE10	SCE20	P
n-6 FAs				
C18:2n-6	13.95 ± 0.17[a]	14.54 ± 0.42[b]	14.28 ± 0.21[ab]	0.010
Σn-6 FAs	**14.26 ± 0.26[a]**	**14.88 ± 0.38[b]**	**14.64 ± 0.21[ab]**	**0.008**
n-3 FAs				
C18:3n-3	4.48 ± 0.29[a]	5.18 ± 0.71[b]	4.88 ± 0.25[ab]	0.050
C20:5n-3 EPA	**2.91 ± 0.15**	**3.58 ± 0.76**	**3.24 ± 0.21**	**0.070**
C22:6n-3 DHA	**8.19 ± 0.30**	**8.22 ± 0.34**	**8.65 ± 0.48**	**0.097**
Σn-3 FAs	**15.58 ± 0.55[a]**	**16.97 ± 1.22[b]**	**16.77 ± 0.89[ab]**	**0.041**

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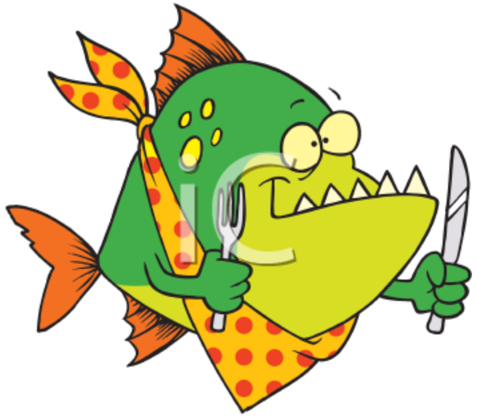
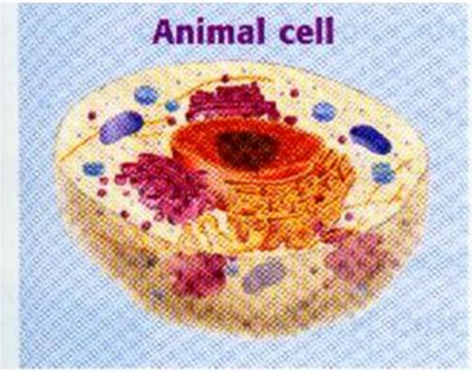
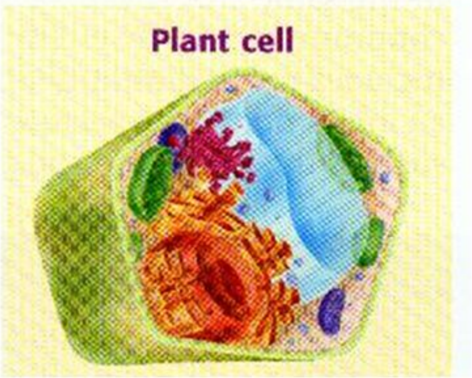
Challenge 2: Rigid cell walls



Main challange for utilization of microalgae in carnivore fish: Rigid indigestible cell walls

ANIMAL VS. PLANT CELLS:





No Cell wall	Cell wall
No Chloroplasts	Chloroplasts

Scalable effective methods for improving digestibility and utilization of microalge in carnivore fish diets?

Scalable effective methods for improving digestibility and utilization of microalge in carnivore fish diets?

- Pelleting vs Extrusion
  - Addressed in project Large-Scale Production of Fuels & Feed from Marine Microalgae. Published in Gong et al. 2017
- Extrusion vs double extrusion
  - Addressed in the COFASP/NRC funded Alger4laks. Publication in progress
- Bead milling as pre-treatment
  - Addressed in the NRC funded project Algae to future (A2F)

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How far is the new protein from the market?

nutrients

MDPI

Review

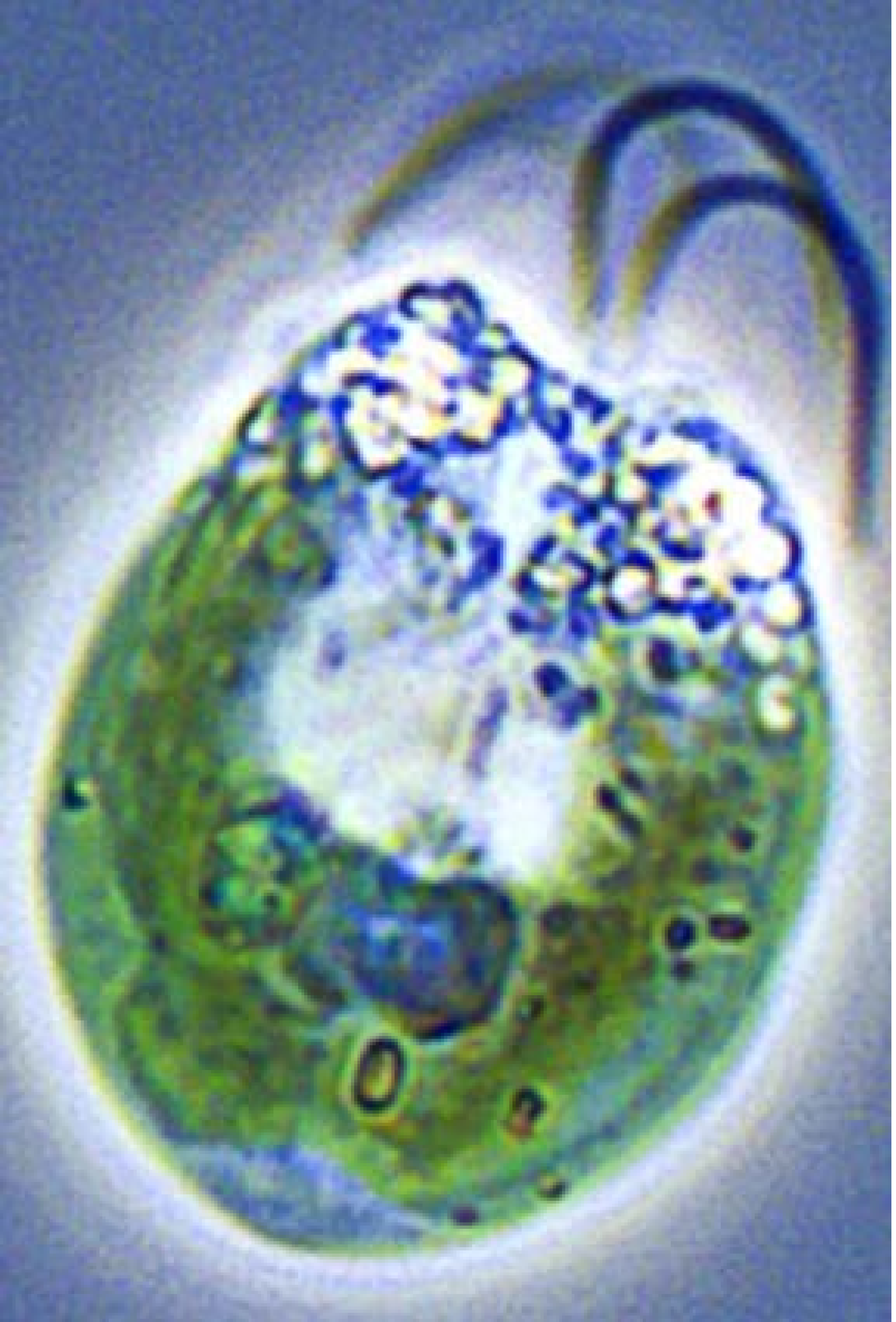
Omega-3 Long-Chain Polyunsaturated Fatty Acids, EPA and DHA: Bridging the Gap between Supply and Demand

Douglas R Tocher [1,*], Monica B Betancor [1], Matthew Sprague [1], Rolf E Olsen [2] and Johnathan A Napier [3]

Nutrients **2019**, *11*, 89

Table 1. Summary of the origins and compositions of some potential new sources of EPA and DHA.

				Composition [a]					
							Total n-3 LC-PUFA		
Product	Development Partners	Source	Type	Lipid Content [b]	EPA [c]	DHA [c]	% of TFA [d]	% of Product	R
AlgaPrime™ DHA	Corbion (TerraVia/Bunge) [e]	Microalgae	Algal biomass	60	0	48	48	28	
DHAgold™	DSM Nutritional Products	Microalgae	Algal biomass	49	1.0	44.4	45.8	22.5	
DHA Natur™	ADM Animal Nutrition	Microalgae	Algal biomass	50–60	0.25	34	34.3	17.2–20.6	
ForPlus™	Alltech Coppens [f]	Microalgae	Algal biomass	61	0.3	29	29.3	17.9	
Nymega™	Heliae Development [g]	Microalgae	Algal biomass	65	~0.1	20	~31	21	
Veramaris® Oil	Veramaris [h]	Microalgae	Oil	100	~16	~34	~54	~54	
Camelina sativa	Rothamsted Research/UoS	GM camelina	Oil	100	20	0	24	24	
Camelina sativa	Rothamsted Research/UoS	GM camelina	Oil	100	9	11	28	28	
Latitude™	BASF/Cargill	GM canola	Oil	100	7	1	12	12	
Aquaterra™/Nutriterra™ [i]	CSIRO/Nuseed/GRDC	GM canola	Oil	100	0.5	10	12	12	
Yarrowia lipolytica [j]	DuPont	GM yeast	Yeast biomass	~50	~50	0	50	25	



To summarize

- Challenges related to (nutritional) quality
  - Low or variable nutrient composition
  - Cell walls reduce digestibiilty
- How do we try to resolve these issues?
  - Disruption of cell walls
- How far are the new protein from the market?
  - Some microalgae are already being used
    - Low quantity
    - Expensive

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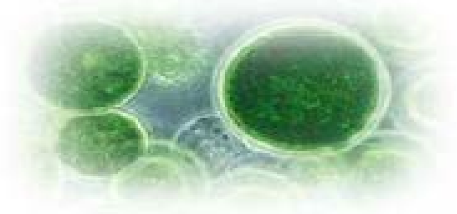
Thank's for your attention



Picture Source: ProAlgae project: Industrial production of marine microalgae as a source of EPA and DHA rich material in fish feed – Basis. knowlege status and possibilities

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