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Seaweed as feed ingredient in aquafeed

– a SWOT analysis

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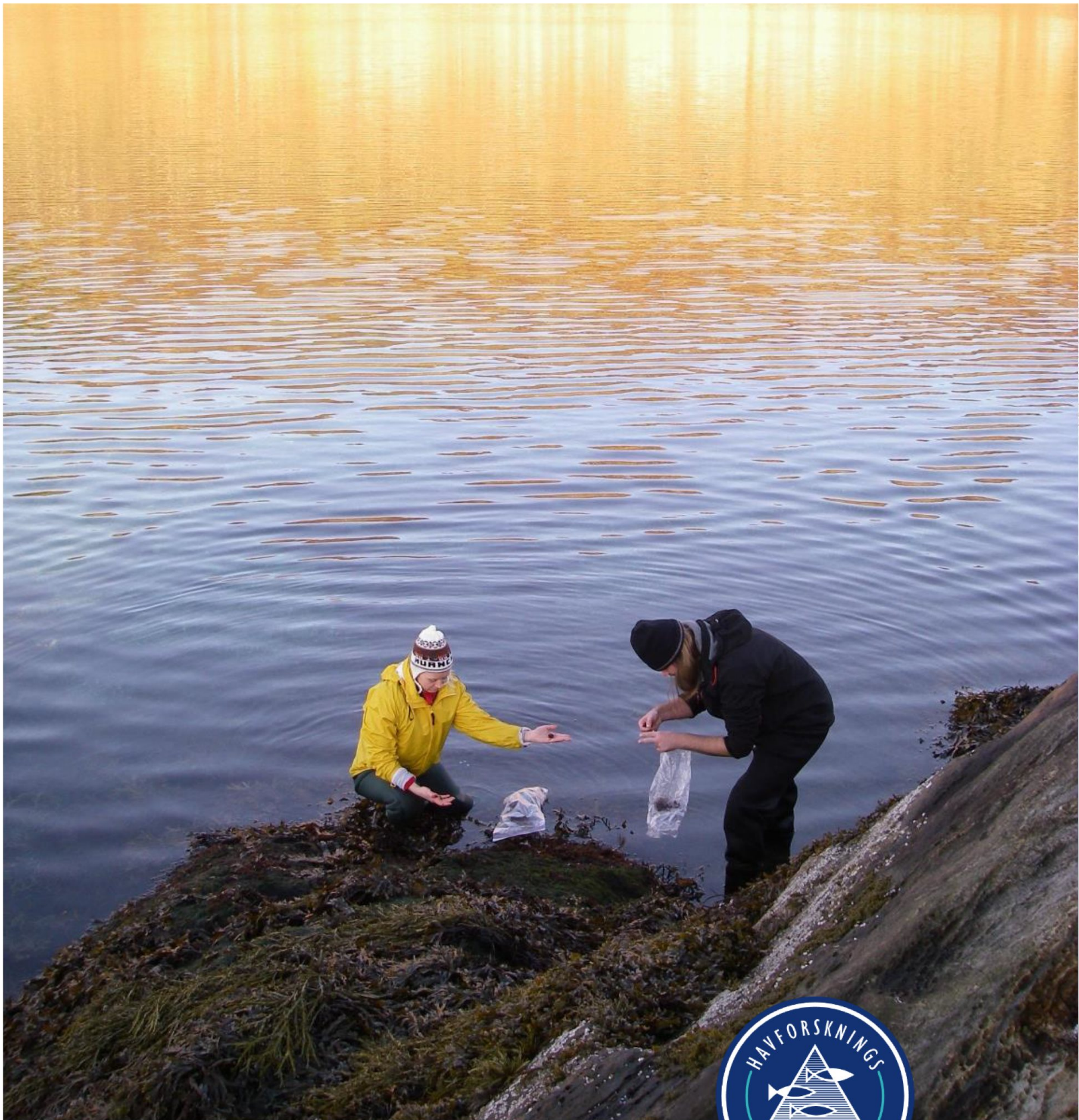

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Project Report

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Seaweed as feed ingredient in aquafeed

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Summary (Norwegian):
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Summary (English):
Finfish aquaculture has been a quickly developing industry during the past three decades and is expected to continue this growth in the foreseeable future. The aquafeed industry has to keep up with this growth and maybe even faster, since many of the traditional forms of finfish culture (e.g. in Asia) are being intensified which often results in the use of formulated feeds. The main ingredients in aquafeed nowadays come from terrestrial sources, with the exception of fishmeal and –oil. Even though it is a well-known fact that a kg of fish fillet needs considerable less resources than a kg of beef or even pork, aquaculture will inevitably put more pressure on land resources. The blue economy aims to produce more food from the sea to satisfy the global need for nutrients. Finfish aquaculture is often used as an example of how to achieve this. Indeed, the potential is large, however this is only possible if we manage to harvest the primary producers from the sea as well. Seaweed is one of the primary producers in the marine food chain, similar to plants in the terrestrial food chain. Although seaweed are taxonomically not plants, many parallels between seaweed and plants exists. Both can be a valuable source of nutrients that can be used by animals higher up the food chain, but both also contain anti-nutritional factors, preventing them from being preyed on by these animals. The effect of a plain soybean meal on the development of enteritis in Atlantic salmon is well known and similar effects are seen of peas and other vegetable products. In commercial diets it is highly processed protein concentrates of these plant products that are used. This removes or reduces many of these anti-nutritional factors and simultaneously concentrates the protein content of the product. Salmon is a carnivorous fish that requires protein, lipid and micronutrients for healthy growth, the requirement for carbohydrates is very low. Seaweed is mainly made-up of carbohydrates that cannot be used by the fish. This raises the obvious questions about post-harvest processing of seaweed to make nutrients more accessible and remove anti-nutritional factors, which currently are underdeveloped or non-existing. A fractionation of the seaweed biomass is needed where high-end products (e.g. alginates) can

offset a large part of the production and processing costs. The lack of seaweed processing and diversification of the processing is the major hurdle for the use of seaweed in aquafeed. This analysis will elaborate on the strengths and weaknesses of using seaweeds in feed for fish and pinpoints future changes that could stimulate (opportunities) or raise barriers (threats) in the application of marine macroalgae in aquafeed.

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Content

1 Strengths

The inherent strength of seaweed for this analysis (aquafeed) will be from a nutritional perspective. There is a decent amount of documentation of nutritional composition of seaweed both from Norway and abroad [1-6]. The most relevant macronutrient from seaweed is protein. Depending on the species and the season, seaweeds can contain varying protein levels (50-300 g/kg dry weight (DW) [1, 2, 6]. The green and red types of seaweed contain the highest protein levels (150-300 g/kg) and the brown seaweed on average the lowest [1, 6]. Of the brown species it is however the kelp species (like Saccharina latissima and Alaria esculenta) that contain the highest protein levels, around 100-200 g/kg [1, 4, 6]. These species are most likely to be cultured on a large scale for food and feed. Generally, seaweed species contain all the essential amino acids required for animal growth and health, including fish. In addition to the higher content in acidic amino acids, some red seaweed (Palmaria palmata) possess a high concentration of methionine which is higher than reported for leguminous pulses [7]. These seaweed species also contain a high concentration of taurine [7], which can be beneficial in fish nutrition and is not detected in plant meals. Many peptides have been identified in marine macroalgae with therapeutic properties [4]. Among them, the antioxidant peptide glutathione has been found in the Norwegian marine macroalgae [8]. In terms of other antioxidant systems, some cysteine-oxoforms metabolites (hypotaurine and cysteine-sulfinic acid) were also detected in the green and the brown seaweeds [8, 9].Seaweed are usually low in lipids, but in some species the typical marine omega n-3 long chain fatty acid (eicosapentaenic acid, 20:5n-3) can contain up to 0.5% (of dry weight) [10]. The ratio between n-6 and n-3 fatty acids is considered an index for evaluating the nutritional value of a dietary lipid source with respect to human and animal development and health. The n-6:n-3 ratio varied between the phyla but also between different species belonging to the same phylum, for example the three seaweeds phyla collected along the Norwegian coast had an n-6:n-3 ratio around 1:1 [1, 2], which does not exceed the ratio of 5:1, as recommended by the world Health Organization (WHO). Furthermore, the red and the brown seaweed are rich source of bioactive lipid metabolites, the oxylipins [8], which act as signaling molecules and provide innate immunity against different stress factors [11]. There are companies pressing oil out of dried seaweed targeting specific markets, but for aquafeed it is an unlikely future ingredient due to pricing [12].Seaweed is rich in iodine. For human consumption this would have its benefits however for fish nutrition it is less of an importance. Certain species like, Laminaria sp. (stortare), currently one of the main species harvested along the Norwegian coast can contain extremely high levels of iodine[1, 13]. At these concentrations it would pose a health risk for consumers, it is unclear whether these high iodine levels would pose as risk for the fish. Julshamn and colleagues (2006) fed Atlantic salmon diets containing up to 80 times their requirement for iodine. After 150 days of feeding, this did not affect their health. Fillet iodine levels were moderately increased [14], which could be beneficial to the nutritional value of these fish for human consumption. Seaweed also contains other essential elements, like calcium, iron, manganese, zinc, selenium, magnesium, and phosphorus. All of these are required by the fish, however there is little known on the availability of these minerals for fish. In their natural environments, seaweeds are exposed to various biotic and abiotic stress factors. As a result, seaweeds contain many forms of antioxidants including vitamins and pigments. Seaweeds are a good source of some water- (B(1), B(2), B(12), C) and fat-soluble (β-carotene with vitamin A activity, vitamin E) vitamins. The water-soluble vitamin C is present in large amounts in brown, green and red seaweeds, such as Gracilaria spp, which contain 25 mg/100 g wet weight [15, 16]. Green seaweed, like Ulva lactuca, can provide as well a high level of vitamin B12 [17]. Moreover, the level of β-carotene found in the seaweeds is high and can exceed those measured in carrots, e.g. in Gracilaria chilensis [18]. Furthermore, brown algae contain high level of the eight forms of vitamin E (tocopherols and tocotrienols) [1, 8], which are known as a strong antioxidant compounds with many beneficial health effects and required by salmon. The exploitation of seaweed has been mainly focused on the industrial production of thickeners, stabilizers or gelling agents in the food industry, such as carrageenan, agar and alginates [19]. These compounds could be used as binders in the feed pellets since they are naturally present in the seaweed meal. Finally, seaweed is rich in many other and unknown bioactive compounds, for an overview please see Holdt and Kraan (2011) [4]. A lot of these bioactive compounds are found in the carbohydrate fraction, such as the polyols, which are the common storage compound of brown algae. This phylum is also a rich source of sulfated polysaccharides [8]. There is not much known about the effect of these compounds in aquafeed, however these bioactive compounds, which are considered as functional food ingredients, have beneficial health effects in humans and mammals [20, 21]. Beyond the nutritional composition, using seaweed as a functional feed ingredient can provide specific benefits to the fish, e.g. preventive health care through nutritional means. However, in a seaweed meal there is a whole collection of compounds and some compounds could be detrimental to the fish's health. The few studies that exist show that a small inclusion of algae (between 2.5 and 10% of the diet composition) in aquafeed resulted in positive effects such as; increase in growth performance, carcass quality, intestinal microbiota, improve stress and immune response and disease resistance [22-27]. For example, the dietary inclusion of Gracilaria or Fucus spp (2.5-7%) into the diets of European seabass (Dicentrarchus labrax) improved the immune and antioxidant response without affecting the growth performances [26]. Moreover, feeding rainbow trout (Oncorhynchus mykiss) with diets supplemented with 5% Gracilaria sp, improved flesh quality traits (higher color intensity and juiciness) and enriched the content of flesh iodine than fish fed the control diet [28]. However, high inclusion of algae (18%, Porphyra sp.) in aquafeed showed impaired growth in thick-lipped grey mullet (Chelon labrosus) when compared with non-supplemented diets [29].

2 Weaknesses

The nutritional composition of seaweed varies highly between different species, but also within species belonging to the same phylum. Nutrient content varies between locations, time of the year, wild vs cultured, etc. For example, the brown algae, *A. nodosum* contains 45 g protein/Kg DW, while the red algae, *P. dioica* contains 310 g protein/kg DW when sampled at the same location at the same day [1, 6]. Moreover, seaweeds are usually low in lipids (0.9±3.7% of dry weight) and do not contain docosahexaenoic acid (22:6n-3 DHA).

Seaweeds are rich in minerals, giving a seaweed meal a (too) high ash content. Certain seaweeds species contain a very high concentration of iodine (*L. digitata*, 10 000 mg/kg DW) [1], manganese and zinc [30]. There is no data available on the availability of these minerals for fish.

Seaweeds accumulate undesirable elements, such as arsenic and cadmium. These concentrations can be so high that the level exceeds the maximum level allowed for the use as a feed ingredients [1, 2, 31, 32].

If a whole seaweed meal is used a large portion will be indigestible complex carbohydrates that will not be used by the fish species. Furthermore, seaweeds contain substances with anti-nutritional activity such as lectins, protease inhibitors, goitrogens, allergens, anti-vitamins, and toxins (e.g. kainic acid), which can reduce the digestibility and bioavailability of other ingredients.

3 Opportunities

Norway has an extensive coastline (100,000 km characterized by fjords and islands), which is among the world's longest and most productive but also has a well-established aquaculture sector offering suitable preconditions for developing large-scale cultivation of seaweed biomass, both wild-harvested and cultivated. There are currently also many projects focused on seaweed cultivation, which can optimize production and reduce costs. Cultivation of seaweed has the advantage of better control over the material and harvesting time can be optimized according to certain nutritional parameters.

Seaweed from long lines can be used not only in feed production but also for production of food, nutraceuticals, fertiliser, soil amendment, fine chemicals, cosmeceuticals and pharmaceuticals. Seaweeds contain many commercially interesting compounds (e.g. alginates). If the industry can develop into a fractionation of the seaweed biomass, where the high-end products (for e.g. cosmetics, food) can offset most of the costs of production and processing, than the remainder can be turned into a protein concentrate. Furthermore, seaweeds in proximity to fish farms, can function as extractive components within a cultivation food web. Reducing the environmental impact of intensive fish aquaculture, integrated multitrophic aquaculture systems add value to the investment in finfish aquaculture by increasing the yield of total biomass produced on a single site.

4 Threats

The major threat is the lack of processing facilities for seaweed at this moment. When looking at the terrestrial production chain it is very well developed compared to the marine production chain (besides fish). A dried whole seaweed meal is not the way forward, it has to be processed into e.g. a seaweed protein concentrate.

Pricing of commodities: this is a threat to any new feed ingredient. Based on the amino acid composition, seaweed is comparable to vegetable proteins. A seaweed protein concentrate therefore has to compete with a soybean protein concentrate for price.

Harvesting seaweeds, specifically the brown algae, using designed trawling equipment, remains controversial as the removal of and interference with natural habitats has the potential to affect local biodiversity and ecosystem integrity, and may contribute to coastal erosion.

5 SWOT analysis

The attributes are ordered in our perceived importance. Every column starts with the most important Strength, Weakness, Opportunity or Threat.

STRENGTHS	**WEAKNESSES**
Vegetable type protein	High concentration of complex carbohydrates
High levels of bioactive amino acids, metabolites and peptides *taurine* *cysteine-oxoforms metabolites* *glutathione, γ-aminobutyric acid (GABA)* *mycosporine-like amino acids*	High concentrations of cadmium, arsenic (inorganic and organic) and mercury High variation in nutrient content (species, geography, season)
Bio-active compounds with antioxidant properties *sugar alcohol metabolites (mannitol, sorbitol)* *sulfated polysaccharides* *Pigments (carotenoids, fucoxanthin)* *oxylipins*	Anti-nutritional compounds *lectins* *protease inhibitors* *goitrogens* *allergens* *anti-vitamins*
Rich in valuable micronutrients, like I, Zn and Mn High abundance of fucosterol and α-tocopherol Binding properties (complex poly-saccharides)	High ash content *iodine* *zinc* *manganese* *calcium* Low in lipid content
OPPORTUNITIES	**THREATS**
Possibility to build the aquaculture production on marine primary producers – Blue Economy	Lack of processing/refinement
Seaweed abundantly present along the Norwegian coast	Low pricing of commodities
Local sourcing of cultivated seaweed	Environmental impact of harvesting wild seaweed
Synergies with existing aquaculture (IMTA)	

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