How can feeding strategies in finfish mariculture be more sustainable?

The world's production of finfish mariculture increased from 1 million tones in 1990 to 7 million tones in 2018 (FAO, 2020). Today, feed used in mariculture is reliant on terrestrial plants, in addition to fish meal and fish oil sourced from wild-captured fish. In the future, the competition for agricultural plants will increase, and the capture of wild fish is limited (Olsen, 2011). The United Nations recognizes an increasing and sustainable food production as a critical part of the 2030 Agenda for Sustainable Development. New ways of feeding strategies are needed if fed mariculture is to increase while meet the demand for a more sustainable food production. With a more sustainable feeding strategy, mariculture could be an important part of reaching several of the Sustainable Development Goals (particularly SDG2, SDG12, SDG13, SDG14 and SDG15). Feed ingredients including alternative terrestrial plant- and animal-based proteins, seafood processing waste, microbial ingredients, insects, algae, and genetically modified plants are increasingly developed and used in mariculture feed (Hua et al., 2019). Here, we want to highlight some of the most promising feed ingredients to a more sustainable and expanding mariculture. First, we will discuss the potential of a more sustainable plant- and animal-based feed production. Thereafter, we will discuss if insect- and algae-based feed production can be a realistic part of future mariculture feed production.

The traditional fishmeal and fish oil usage in mariculture

In the 1990s, the fish feed was composed of approximately 90% fishmeal and fish oil. Today, about 70-80% of fish feed is made up of plant-based ingredients (Muri, 2021). The most important vegetables are soybeans, sunflower, rapeseed, corn, fava beans, and wheat. These vegetables are important sources of protein, carbohydrates, and fat. An increasing population results in a need to produce larger quantities of sustainable food (SDG 2), consequently, is the production of sustainable feed used in mariculture a high priority (Gatlin et al. 2007). Research focus on reducing the trophic level to enable a more energy efficient industry (SDG12). When moving from one trophic level to a higher, 90% of the energy is lost (Olsen, 2011). Therefore, it is sustainable beneficial to replace fishmeal and fish oil completely with vegetable substitutes. Some candidates for this are oilseeds, legumes, and cereal grains such as barley, canola, peas/lupins, and cottonseed.

The main problem with increasing the amount of vegetables and reducing the use of fish meal and fish oil is that certain proteins and highly unsaturated fatty acids (HUFA) are needed, especially in the production of carnivorous species. Until the problem of HUFA can be solved, reduction or removal of fish meal and fish oil in the feed will not be possible (Olsen, 2011). Current research on salmon also shows that not using fish meal in the feed for fish below the size of 30g significantly reduces the growth of the fish (Burr et al. 2012).

Using fish waste instead of wild-captured fish as a recourse to animal protein

Finfish in mariculture are mostly carnivorous, and consequently, it is unnatural to change their diet entirely to primary producers. Therefore, it makes sense to investigate more sustainable opportunities for fish-based feed (SDG12 and SDG14). New methods and technologies allow more efficient use of fish waste generated in huge amounts as a feeding alternative by converting fish waste into a value-added product, for example

into fish protein hydrolysate (FPH) (Siddik et al., 2020). Utilization of the fish waste serves several purposes, it saves costs (SDG 8) and reduces fisheries waste (SDG 12) (Tugiyono, 2020).

The Norwegian research institute SINTEF Ocean has for many years worked with total utilization of biomass from the seafood industry to create high-quality ingredient products for use as fish feed, food, and pharmacy. The work has resulted in several successful projects of fish waste utilization both as feeding alternatives and some other valuable products (SINTEF, 2020). Fish waste is a valuable raw material that requires wise production methods to become real sustainable alternatives. The utilization of fish waste will contribute to a good circular economy (SDG 8) because of the use of unusable materials which would otherwise be garbage and a source of pollution (SDG 12 and SDG 13).

Insect, algae, and zooplankton as a future low trophic ingredient to protein

Insects, micro- and macroalgae and zooplankton are ingredients at low trophic levels, and thereby very energy efficient. In addition, they are not a significant part of the human food chain, and we thereby avoid using ingredients which humans can consume directly. With this in mind, the use of these ingredients in finfish mariculture can be a part of achieving SDG2, SDG12, SDG13, SDG14 and SDG15.

Researchers are trying to figure out if insects can be used as an alternative sustainable raw ingredient in finfish mariculture feed production. Currently, small-scale experiments with insects as an alternative ingredient in mariculture feed production have shown promising results (Cadillo-Benalcazar et al. 2020). There haven't been any negative effects when fish oil and fish meal were replaced with insects in the diet of rainbow trout. However, when the fish is fed by insects it will result in a lower content of n-3 fatty acids and a different color on the fillet, a consequence can be that the consumer does not prefer the product (Turek et al. 2020). Technical, financial, and regulatory barriers still limit the utilization of insects in finfish feed production (Sogari et al. 2019).

Other promising contributors to sustainable feed for mariculture are macro- and microalgae. They are primary producers on the lowest trophic level, and thereby very energy efficient. One of the advantages of macroalgae is that it contains HUFA and variable content of protein (Olsen, 2011). Development in this area is still to be made, but production costs have the potential to be relatively low (SDG 8). Today, it is not economically beneficial to use algae as a major contributor to raw materials in mariculture feed. This is due to the absence of an industrial sector supplying raw material from macro- and microalgae for feed production, and thereby the prices make it unfavorable in competition with other ingredients. However, it is economically useful as sustainable supplements, such as ingredients to complete requirements in essential fatty acids, trace elements, or active components for health (Gouvello & Simard, 2017).

Zooplankton is a key connection in the aquatic food web, and also an essential component in all aquatic ecosystems (Boskurt and Tuğyan 2020). Zooplankton is live food and a significant ingredient in artificial fish diets (Onianwah 2018). Zooplankton is small floating or weakly swimming organisms that drift with water currents, such as herbivore copepods and krill (Lawrence 2016). Essential nutrients such as HUFAs,

high-quality proteins, and minerals will be incorporated into the feed by using zooplankton (Maehre, Hamre, and Elvevoll 2013). Zooplankton-fed marine fish larvae have a high survival rate and good growth (Boskurt and Tuğyan 2020).

In conclusion, a sustainable expansion of finfish mariculture requires a change in feeding strategies. To produce more sustainable feed, we need to produce and harvest from lower trophic levels. We should continue to let plant-based ingredients be a significant proportion in finfish feed, in addition to exploring new ingredients like insects, macroalgae, and zooplankton. The latter ingredients are in addition fulfilling the goal of avoid feed from the human food chain that could have been consumed directly by humans. This solution enables a more energy-efficient and sustainable production, and thereby participation on achieving SDG2, SDG12, SDG13, SDG14 and SDG15. In addition, modern technologies allow the processing of fish waste and leftovers into a protein source and other value-added products which can be used again in finfish feed. Thus, using a recycled product and contributing to the sustainable circular economy (SDG8).

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