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Transforming excess nutrients in eutrophic coastal waters to marine protein for feeds

by Daniel Taylor and Jens Kjerulf Petersen, Danish Shellfish Centre, DTU Aqua, Denmark

Human population density and utilisation of lands for cultivating foods have intensified in coastal regions over the past century. This intensification has dramatically affected the biological and chemical processes in coastal ecosystems through an increase in the flow of nutrients, principally nitrogen and phosphorus, from the land and atmosphere to the sea.

Essentially, the more that the land is fed (fertilised) and the more we feed ourselves (food plus fuels), the more we feed coastal waters with nutrients caused by agricultural runoff, wastewater, and atmospheric deposition.

As coastal waters become over-enriched, biological functioning changes with often long-term consequences. One of many symptoms is the increased growth and concentration of phytoplankton (single celled plants).

Enriched waters can become so productive with phytoplankton growth that sunlight will not sufficiently reach depths to support aquatic plant life on the sea floor and valuable plant habitats like seagrass meadows are lost. Further increases in phytoplankton concentrations can lead to oxygen depletion, when dead phytoplankton cells decay on the sea bed.

For the past few decades, the improvement of coastal water quality has been a locus of policy development in many regions around the world. There have been impressive achievements in the implementation of these policies, notably in the improvement of wastewater treatment.

Nevertheless, many coastal water bodies, such as those in Northern Europe, including the Baltic proper, are still considered heavily affected by excess nutrient run-off and will likely continue to be so for years to come.

Nitrogen inputs into coastal waters originate from point sources (eg water treatment plants, fish farms), non-point/diffuse sources (eg agricultural lands, groundwater discharge), or atmospheric (eg volatilised ammonia or combustion by-product absorption).

Following modifications and improvements in water quality management programs, diffuse sources of nutrients are the most significant. Treatment methods designed to minimise nutrient introduction into coastal waters are abundant in implementation.

Classic examples of such treatment methods include restrictions in use of fertilisers, constructed wetlands, settling ponds, vegetative riparian buffer zones; and more recently, systems of ‘precision agriculture’.

Although much progress has been made in reducing nutrient flows into coastal waters, the efficiency of further implementation rapidly diminishes and are also often more expensive to implement.

Furthermore, decades of enrichment has a legacy of enhanced enrichment of sea floor sediments, which will be a persistent source of nutrients by multiple processes (termed 'internal loading'), and can only be mitigated within the aquatic environment.

Mitigation mussels

One innovative means of mitigating nutrient enrichment in coastal waters is to leverage a part of coastal biology – shellfish bivalve water filtration. Mussels, oysters, clams, and other bivalves feed by filtering particles out of the water; phytoplankton is a primary source of food for these animals.

Active cultivation of bivalves and focus on bivalve reef restoration have demonstrated the filtration impact these populations can exhibit. Standard mussel farms can filter hundreds of thousands of cubic metres-per-hour. Phytoplankton and organic matter are assimilated in the mussel body or immobilised to the sediments, trapping a significant portion of nutrients in enriched waters.

Much work has been done to analyse the 'ecosystem services' provided by bivalves over the past decades by numerous researchers, mostly in the USA and northern Europe. Over a decade of conceptualisation and research at the Danish Shellfish Centre (DSC) - a section within DTU Aqua, Technical University of Denmark – has focused on leveraging bivalve filtration in active cultivation as an intensive mechanism to reduce the magnitude of eutrophic conditions in western Baltic waters; termed 'Mitigation mussel culture'.

By harvesting the mussels, the nutrients that are first consumed by phytoplankton and then converted into mussel biomass, are removed from the ecosystem. Employing cultivation techniques adapted from the conventional mussel aquaculture industry, high densities of mussels can be grown in targeted regions, with the potential to remove several metric tonnes of nutrients from coastal waters per harvest (Petersen et al, 2019) This mode also serves as a means to utilise vast numbers of mussel larvae, which are normally consumed as zooplankton or fail to settle. While aquaculture mussels (which show up on dinner plates) do also provide this service, 'mitigation mussels' are typically harvested with minimal manipulation and at a shorter growing period to reduce costs and maximise nutrient extractive potential – they tend to be considerably smaller than the mussels that are found at the market or restaurants.

As a nutrient mitigation measure, mitigation mussel cultivation has been in adopted in the plans for future efforts to reach good ecological status in Danish coastal waters. In Denmark, a proposed goal is to harvest 100,000 metric tonnes of mitigation mussels annually, which will result in removal of 1-2,000 tonnes of nitrogen, corresponding to 8-15 percent of the national reduction demand in Denmark.

Mitigation mussel meals: Returning lost nutrients

How do aquafeeds and other forms of aquaculture fit into this equation? The concept of integrating filter feeding organisms, such as mussels, into the production of higher trophic species has been popularised by many, often termed 'Integrated Multitrophic Aquaculture' or more accurately just 'Multitrophic Aquaculture'.

As a source of nutrients, however, in most countries this contributes a negligible amount of nutrients relative to the larger terrestrial coastal loading.

As mitigation mussels tend to be smaller and less uniform in size than those cultured for human consumption, the production of feed meals has been the most attractive avenue for utilisation. The growing demand for protein sources for feeds with balanced amino acid profiles has required expanded generation and inclusion of fishmeal alternatives.

Meals produced from blue mussels generally have similar amino acid profiles to fish meals (Jönsson and Elwinger, 2009), with total crude protein levels of 65-71 percent. Concentrations of amino acids typically requiring supplementation in replacement diets, such as methionine and taurine, are similar to fishmeal profiles (Árnason et al, 2015).

Mussel tissues contain important pigments and anti-oxidants, including mytiloxanthin, a pigment unique to shellfish, which outperforms astaxanthin in hydroxyl scavenging (Maoka et al., 2016). Furthermore, full fat mussel meals exhibit attractive proportions of LC-PUFAs such as DHA, DPA, and EPA (Árnason et al, 2015).

In agriculture husbandry diets, high levels of inclusion have demonstrated positive effects on egg laying hens (Afrose et al, 2016), and digestibility in porcine feeds (Nørgaard et al, 2015).

A limited number of studies in finfish species have demonstrated high digestibility in Arctic charr (*Salvelinus alpinus*) and Eurasian perch (*Perca fluvialtilis*) (Langeland et al, 2016), as well as increased palatability in carnivore diets with high plant inclusion (Nagel et al, 2014). Interestingly, the biochemical composition of mussel tissue can be influenced by the local conditions of growth, due to different phytoplankton community constituents (Pleissner et al, 2012), as well as reproductive state; as glycogen concentrations and carotenoid pigments increase immediately before spawning.

Determining differential composition patterns in the future may provide opportunities for specified meals; however, this requires further investigation provided large-scale production of meals will likely blend material from multiple sites and times.

Mussels, in mitigation culture, therefore pose an attractive source of protein as they assimilate phytoplankton already overabundant in the environment (zero managed feed input) while providing positive ecological feedbacks. Such feedbacks (ecosystem services) in other mitigation mechanisms are largely compensated by direct financial support or cost offset schemes. In essence, recycling 'lost' nutrients back into the food system and improving the local environment along the way.

Nevertheless, like any good story, there are challenges ahead. Expanded production of mitigation mussels requires optimisation of nutrient extraction within limited space that also minimises conflict with other uses of coastal waters and vested interests in the seascape.

The natural environment can also pose hurdles to expansion: whether hydrodynamic conditions are suitable, natural mussel settlement is sufficient, and predator pressure (ie eider ducks) are manageable. In policy circles, from local to regional, determining how and where to manage nutrients is coloured by a high variety of perspectives.

As this mechanism aims to reduce nutrients already within the marine environment, mitigation mussel culture is intended to supplement existing nutrient management programmes, and this concept is an on-going point of debate.

Lastly, and which is essential in terms of economic viability, processing of mussel meals and streamlining production will require further innovation. Processing challenges of transforming mitigation mussels to a meal are rooted in the high-throughput separation of the shell from the tissue before subsequent meal production.

Conventional steaming and vibratory separation methods are relatively expensive, while alternative methods of 'juicing' or other form of separation without preliminary shell exclusion generally results in meals with high ash content from retained shell parts.

Current research

Recently, two projects administered by DSC were funded to evaluate optimisation techniques for maximising nutrient extraction in mitigation units while documenting their ecological impacts.

The BONUS OPTIMUS project has pulled together a research consortium from four countries and nine partners for the development of mitigation culture in the western Baltic for the subsequent production of mussel meals as a fishmeal alternative.

Feeding trials undertaken in OPTIMUS include replacement in salmonid diets. The nationally funded project, MuMiPro, brings together 15 partners evaluating optimal cultivation techniques in eutrophic Danish waters for large-scale production of organic mussel meal.

The ambition of both projects is to demonstrate means to produce mitigation mussels that maximises their positive ecological footprint at an economically viable rate. This includes further development of processing mussel meals for animal feeds, and ultimately the high growth aquafeed market.

Testing and optimisation of alternative processing techniques are currently under investigation in the MuMiPro project. Finding the combination of maintaining a good nutritional profile and minimising processing costs, like all other aquafeed ingredients, is a constantly evolving process.

The combined aims of these two projects are to propel the development of mitigation mussel culture as a nutrient mitigation tool and processing techniques for a high-quality meal.

For more information on research at the Danish Shellfish Center: http://www.skaldyrcenter.aqua.dtu.dk/english

For more information on the MuMiPro project: http://www.mumipro.dk/

For more information on the BONUS OPTIMUS project: http://www.bonus-optimus.eu

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