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# Integrated multi-trophic aquaculture systems and circularity assessment

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**Results showed circularity improvements of up to 90 percent for water recirculation and 80–90 percent for bioremediation**



This study identified two basic pillars – nutrient management and resource use efficiency – as the most relevant circularity attributes for

IMTA systems. Bioremediation indicators, together with the efficiency indicators in terms of feed, water, energy, and infrastructure materials used, were selected to evaluate the circularity performance of four IMTA trials in three aquaculture facilities in Ireland, Brazil and South Africa. Photos of two of the species used in the study, the South African abalone (*Haliotis midae*, left) by derekkeats, via Wikimedia Commons; and the purple sea urchin (right; *Paracentrotus lividus*) by Diego Delso, via Wikimedia Commons.

The circular economy is a model of production and consumption where cleaner and more competitive practices focus on saving and recovering resources, and a harmonized definition of the circular economy should address the importance of biological flows and the role of aquaculture in producing renewable biological resources. The concept of circular aquaculture can be addressed in many ways, but generally, circularity in aquaculture includes the adoption of practices regarding waste management, the recycling of nutrients, or the incorporation of novel ingredients in feeds **derived from the bio-economy** (<https://doi.org/10.1111/raq.12766>).

Integrated multi-trophic aquaculture (IMTA) is a circular production system where different species such as fish, shellfish, and seaweed are strategically integrated/linked to create a symbiotic relationship that contributes to reducing the impacts on the environment. Within IMTA systems, uneaten feed and nutrient losses can be recaptured by other organisms and converted into valuable nutrients for harvestable seafood and crops. Fish excrete nitrogenous and phosphorus waste, the dissolved component of which can be utilized by cultivated seaweed species as a nutrient source for growth, thus reducing nutrient levels in the water and preventing eutrophication. Additionally, filter-feeding organisms such as mussels and oysters can help in the removal of excess nutrients as particulate matter by efficiently filtering water.

In addition to the fact that most circular economy (CE) metrics focus on the technical cycle and materials from non-renewable resources, none of the approaches we reviewed at the farm level fulfill the particularities of aquaculture (even less of integrated multi-trophic production). The diversity of aquaculture systems makes it challenging to determine the circular profile of the sector using a single approach.

This article – summarized from the **original publication** (<https://doi.org/10.3390/fishes9050165>) [Checa, D. et al. 2024. Circularity Assessment in Aquaculture: The Case of Integrated Multi-Trophic Aquaculture (IMTA) Systems. *Fishes* 2024, 9(5), 165] – reports the results of a study of three different IMTA production systems (known as IMTA laboratories) that were evaluated by applying sector-specific circularity indicators.

**New partnership  
in fish processing**



(<https://marel.com/en/news/marel-and-mmc-first-process-unveil-strategic-partnership/https://marel.com/en/news/marel-and-mmc-first-process-unveil-strategic-partnership/?source=Globalseafoodalliance>).

## Study setup

This study explored the potential principles embedded in IMTA and the existing alternatives to quantify circularity. It involved four trials at three different IMTA laboratories: the IMTA lab at the Marine Institute in Ireland growing salmon, oysters, seaweed and urchins; the IMTA lab at the Federal University of Rio Grande in Brazil growing tilapia, Pacific white shrimp and seaweed; and the IMTA system at the Buffeljags Abalone farm in South Africa growing abalone, the green alga *Ulva*, and sea urchins.

Two basic pillars (nutrient management and resource use efficiency) were identified as the most relevant circularity attributes for IMTA systems and were quantified through aquaculture-specific indicators. Bioremediation indicators, together with the efficiency indicators in terms of feed, water, energy, and infrastructure materials used, were selected to evaluate the circularity performance of four IMTA trials in three aquaculture facilities in Ireland, Brazil, and South Africa. All species were cultivated in various combinations with several low-trophic species in these IMTA trials to evaluate the improvement in circularity compared with corresponding monoculture conditions.

For detailed information on the experimental design, systems and animal husbandry; and data collection and analyses, refer to the original publication.



### Conscious coupling: Can IMTA gain a foothold in Europe?

Integrated multitrophic aquaculture (IMTA) isn't widely practiced in Europe but new findings indicate that farming multiple species on one site can work.



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## Results and discussion

Circular economy strategies offer a way to make better use of resources and produce less waste. This study offers insights regarding the role of IMTA in the transition toward more circular aquaculture. It evaluated the performance of IMTA production systems, which have been shown to be suitable systems to increase circularity.

In the Irish IMTA lab, Atlantic salmon release nutrients into the surrounding water, native oysters filter out particulate nutrients while the dissolved fraction is extracted by seaweeds that absorb dissolved minerals and carbon, and spiny sea urchins are fed with the seaweeds grown in this IMTA system. The Brazilian IMTA lab cultivates the most effective biomass ratios of white shrimp, tilapia, and sea lettuce in BFT systems, where organic material and nutrients are regulated. Finally, the South African IMTA lab demonstrates the feasibility of increasing recirculation in the commercial abalone-*Ulva* integrated systems. The pilot commercial-scale urchin-*Ulva* system is being run in the same way but at 90 percent recirculation, largely due to energy cost savings as the seawater needs to be heated to 25 degrees-C for the warm water urchin to grow. This has been run successfully in a fully grown-out trial.

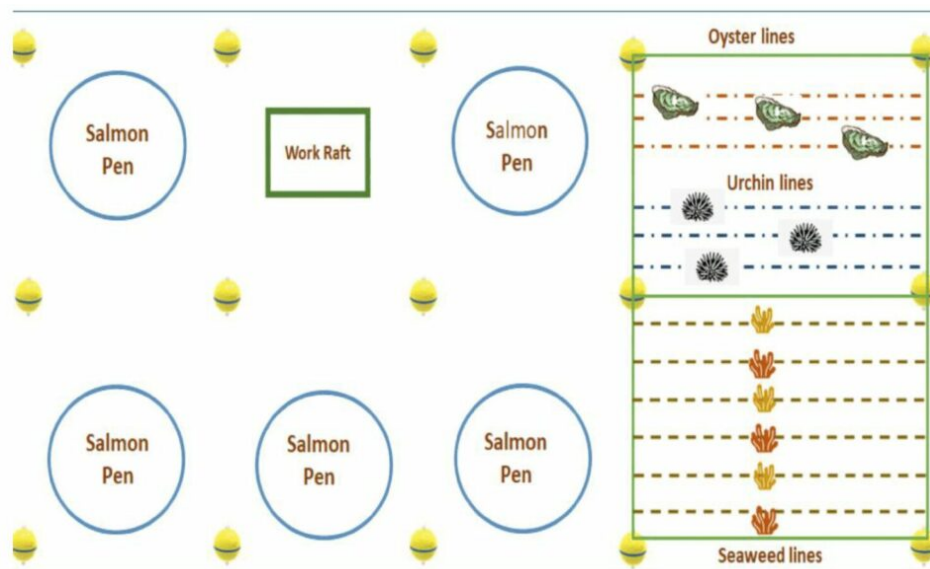


Fig. 1: Irish IMTA lab design – the low-trophic grid with oysters, seaweeds and urchins lies adjacent to the salmon pens within the licensed aquaculture site.

Based on the premise that IMTA performs as a circular system, the present work reveals the need for definitions of metrics. Methodology was developed to allow for the combined assessment of different indicators that can be pertinent to the evaluation of different IMTA systems at multiple scales. The metrics reflect the two principal pillars of aquaculture impacting circularity: nutrient management and the use of resources. The natural capacity of extractive species to assimilate nutrients from the water is evidenced through the quantification of the corresponding indicators. However, the benefits achieved due to the incorporation of macroalgae contribute not only to bioremediation but also to the increased resilience of systems to harmful algal blooms and other adverse events (e.g., chemical/oil spills) (e.g., abalone in the South African IMTA lab with 100 percent recirculation that can isolate the system from the surrounding environment for short (3–4-day) periods.

Fig. 2: South African IMTA lab: (a) abalone/*Ulva* system; (b) urchin/*Ulva* system. Adapted from the original.

Given the relevance of bioremediation as a circular benefit of IMTA, more precise approaches are recommended to determine nutrient budgets. In mass balance approaches, there are many variations that can be incorporated for nutrient loading estimates, making them more appropriate than the use of static input values. Moreover, the present assessment was not entirely performed with primary data, and secondary sources were needed (e.g., assimilation efficiency and the individual growth of urchins or the uneaten fraction of fish in Ireland). Additionally, the respiration and pseudofeces from low-trophic animals in open systems were not quantified and were thus excluded from the nutrient management indicator. Finally, the nutrient mitigation capacities of IMTA systems in open environments are strongly influenced by different factors that limit the nutrient retention capacity of low-trophic species, which should also be considered.

Regarding the use of resources, the Brazilian and South African IMTA (urchin system) labs notably improved feeding performance, as both systems incorporated circular ingredients. Brazil showed circularity attributes for the reduction in FCR, meaning a reduction in resource use. The linearity reduction due to the totally circular feed based on poultry industry by-products in the Brazilian IMTA lab is aligned with the global trend of reducing the demand for fishmeal in the aquaculture sector.

Further assessments would be needed to evaluate if the incorporation of circular ingredients could compensate for an increase in the use of resources due to lower nutritional functionalities of novel feeds based on non-processed ingredients (e.g., urchin fed with fresh *Ulva*). Strategies oriented to increase the digestibility and palatability of formulated feeds would lead to more efficient use of resources, and thus, the consideration of apparent digestibility coefficients (ADCs) of fed species within the circularity assessment would provide a more comprehensive overview of the pillar of resource use.

Fig. 3: N mass balance in the urchin-*Ulva* system. Adapted from the original.

The reduction in energy consumption enabled by water recirculation is particularly beneficial in the South African context. Electricity use for seawater pumping is a major cost of these operations. South Africa also currently has an intermittent electricity supply, and the recirculation reduces the demand for farm electricity generation (from diesel generators) for periods with daily outages. This means that the system can better deal with the frequent electricity outages if the recirculation rate is high, as less water needs to be heated to 25 degrees-C. The Brazilian IMTA lab is an intensified system that is comparatively less efficient than pond systems in terms of energy consumption.

Fig. 4: Brazilian IMTA lab design. Adapted from the original.

Regarding infrastructure, the present study considered the lifespan as a fundamental parameter included in the indicator. Generally, better maintenance or the substitution of infrastructure elements with increased durability would increase the functionality and thus the circularity.

The study of specific indicators, in particular the Material Circularity Indicator, **MCI** (<https://doi.org/10.1016/j.giq.2006.04.004>) – proposed by the Ellen MacArthur Foundation, provides indication on the “degree of circularity” of materials composing products. It has some similarities with Life Cycle Assessment (LCA), but it is more focused on the flow of materials – would provide insight as part of studies of low- trophic aquaculture systems, in which infrastructure and equipment were identified as key elements within the environmental profile.

For all resource aspects, it may be relevant to highlight that the metrics suggested are oriented to evaluate the production itself (the gate-to-gate approach); thus, value chains of aquaculture products are out of the scope, except for the consideration of the origin of feed ingredients (the linearity aspect). Additionally, in the resource use pillar, the evaluation of other potential resource uses, such as fertilizer, antifouling agents, antibiotics, and other chemical agents or products, was excluded, as these were not reported during the operation of each lab.

Finally, this work demonstrates that circularity can be measured at the level of the fish farm, encouraging doing so in a simplified way while bringing the aquaculture sector closer to circular economy progress monitoring. A metrics-based circularity assessment is promoted using a broad approach that is applicable to all multi-trophic production systems. However, data availability is a major constraint, and there is still much room for improvement to increase the robustness of the results obtained, allowing comparisons between similar production systems.



## Perspectives

The lack of specific definitions of circular aquaculture and standardized methodologies might discourage aquaculture producers from identifying and communicating strategies that contribute to increasing circular performance. The present study provided a definition of indicators that reflected in a simple but robust way the efficiency of aquaculture production from the perspective of circularity. The bioremediation, feed, water, energy, and infrastructure indicators would allow non-LCA practitioners to monitor cultivation performance without significantly increasing efforts in data collection and impact evaluation. The circularity indicators expressed here were not intended to be exclusive to LCA approaches, but rather, they complement and potentially encourage the sector to evaluate its contributions to the circular economy.

Our results confirmed that multi-trophic aquaculture systems perform in line with the circular attributes embedded in the essential definition of bioremediation. Metrics for bioremediation would promote the standardization of nutrient recycling rates, from which the effectiveness of the systems could be evaluated. In addition to bioremediation, complementary indicators applied to IMTA provide evidence for the implementation of resource efficiency strategies, which further ensures the alignment of these systems with the circular economy.

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