Goal and Scope Definition for Life Cycle Assessment of Integrated Multi-Trophic Marine Aquaculture Systems

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ABSTRACT

Integrated Multi-Trophic Aquaculture (IMTA) has been regarded as an environmental management concept that can minimize the environmental impacts of conventional monoculture aquaculture farms while expanding their economic base. These characteristics of IMTA systems hold as long as (1) there are no significant trade-offs between the discharge reduction and the life cycle environmental impacts of the IMTA infrastructure; and (2) the co-cultured species in the IMTA system constitute commercial species produced at scales that yield a profit. In this study we use Life Cycle Assessment (LCA) to analyze the environmental trade-offs between monoculture and IMTA systems. We do this by posing two questions: 1) what are the trade-offs for small and medium enterprises (SMEs) considering to move from monoculture aquaculture practice towards IMTA; and 2) what are the trade-offs comparing IMTA species with their conventional monoculture alternatives. Our hypothesis states that the level of integration of the productive activities of the co-cultured species (e.g., bivalves, echinoderms and algae) into the existing monoculture (e.g., finfish) productive activities will determine the magnitude of the trade-offs. Quantification of trade-offs is ongoing as part of the EU FP7 IDREEM (Increasing Industrial Resource Efficiency in European Mariculture) project. We here report our first conceptual results consisting of a scoping framework to be further applied in the project.

Keywords: Sustainable fish production, aquaculture, IMTA, LCA

1. Introduction

Aquaculture, which includes marine fish farming and in this paper refers exclusively to marine systems, faces increasing pressures as demand for seafood products grows while traditional wild fisheries are in decline (FAO, 2012). Integrated Multi-Trophic Aquaculture (IMTA) is the combined cultivation of multiple commercially farmed species that belong to different trophic levels in the food chain. In an IMTA system fish are farmed together with other species including bivalves (such as mussels and oysters), echinoderms (such as sea urchins) and algae or seaweed creating a more efficient, cleaner and less wasteful production system. IMTA allows nutrients from fish farms that are otherwise lost to the environment to be turned into useful products as they are utilized by these additionally grown species. IMTA is considered as one of the solutions to concerns about the future sustainability of aquaculture by increasing productivity and profitability while also reducing waste and over-reliance on raw materials from wild fish stocks.

The FP7 European research project IDREEM (Increasing Industrial Resource Efficiency in European Mariculture) aims to develop and demonstrate such IMTA technologies protecting the long-term sustainability of European aquaculture. The IDREEM project aims to demonstrate the benefits of IMTA through pilot commercial-scale testing, field research and modelling in collaboration with seven European small and medium enterprises (SMEs) paired to local Research and Technology Development (RTD) institutes (SME/RTD pairings). Interdisciplinary research within IDREEM will examine the obstacles and risks of using IMTA systems and apply and develop tools to overcome these constraints, whether they are economic, environmental, technical, social or regulatory. One of the tools applied is Life Cycle Assessment (LCA), which we use for answering two questions: 1) what are the environmental trade-offs for SMEs considering to move from monoculture aquaculture practice towards IMTA; and 2) what are the environmental trade-offs comparing IMTA species with their conventional monoculture alternatives.

The LCA work in IDREEM started with an LCA training of the different SME/RTD pairings. The goal of this workshop was to get the members of the pairings familiar with the main concepts of LCA and to familiarize them with the data collection needed for the LCAs. Following the LCA training the goal and scope definition and inventory analysis were started up. As a first step in the data collection, the present

finfish productive systems (monoculture, baseline or before IMTA systems) of all SMEs were described qualitatively. This included describing all relevant unit processes of each SME. As a second step, quantification of the inputs and outputs of the unit processes of the monoculture systems is currently taking place.

This paper presents first the methodology used to describe the SMEs monoculture and IMTA systems and second our first conceptual and qualitative results addressing the relation between questions posed, type of analysis needed and levels of integration achieved in IMTA. In the next 2 years of the IDREEM project quantitative LCA results will be produced and hopefully used in combination with the conceptual outcomes of this paper.

2. Methods

We started by qualitatively describing the current monoculture SME systems. As a first step in the qualitative description of the monoculture systems and keeping in mind the future comparison with the IMTA systems, the decision of assessing the SMEs monoculture systems in a detailed manner was made. The intention of this decision was to have as much data as possible available in an early stage of the project, including the SMEs' productive processes and activities, their material inputs and outputs and some ideas about their supply chain and waste treatment. A detailed description allows for a future aggregation while a "black box" type of description does not allow for disaggregation anymore neither for a detailed data collection in a later stage of the project. A detailed description was also expected to enable a better understanding of the true integration level of the IMTA species into the existing monoculture systems. Although the aim is to be as detailed as possible in the data collection the feasibility of this, of course, still depends on the availability of data within the SMEs.

The right part of Figure 1 shows a detailed scheme of an aquaculture production system, some general inputs and outputs but without showing the supply chain of materials for clarity of the graph. All inputs to individual processes are supplied by another productive system (upstream processes) or extracted from nature (environmental inputs). The left part of Figure 1 shows the "black box" aggregated type of description of the same system. The black box description is a simplified alternative to describe the monoculture systems, in which the material flows within the SME are not described.

As a second step in the process of qualitative data collection, pairings listed the activities (unit processes) performed and outsourced by each of them for their current monoculture production. A description of the practices used in each of the processes was also described as this helped in defining material inputs and outputs. The list of unit processes provided by each SME constitutes the foreground processes, for which data (primary data) will be collected by the pairings. All other economic activities in the supply chain of the SMEs i.e. upstream supply processes or downstream waste treatment processes will be described using literature or other secondary data sources. The monoculture LCAs consist of attributional cradle-to-gate analyses and do not include consumption of fish as part of the downstream processes. The boundary of the monoculture LCAs is thus at the gate of the SMEs, which depending on the activities of each SME, can be different. The right panel of Figure 1 shows common unit processes for all the SMEs, as well as possible boundaries and generic inputs and outputs to the monoculture productive processes.

Additionally to the monoculture activities, the pairings also described their preliminary plans for their IMTA systems. With respect to the level of integration of the planned IMTA systems (i.e. production activities and infrastructure) into the current monoculture systems, the proposed IMTAs are likely to move between two extremes.

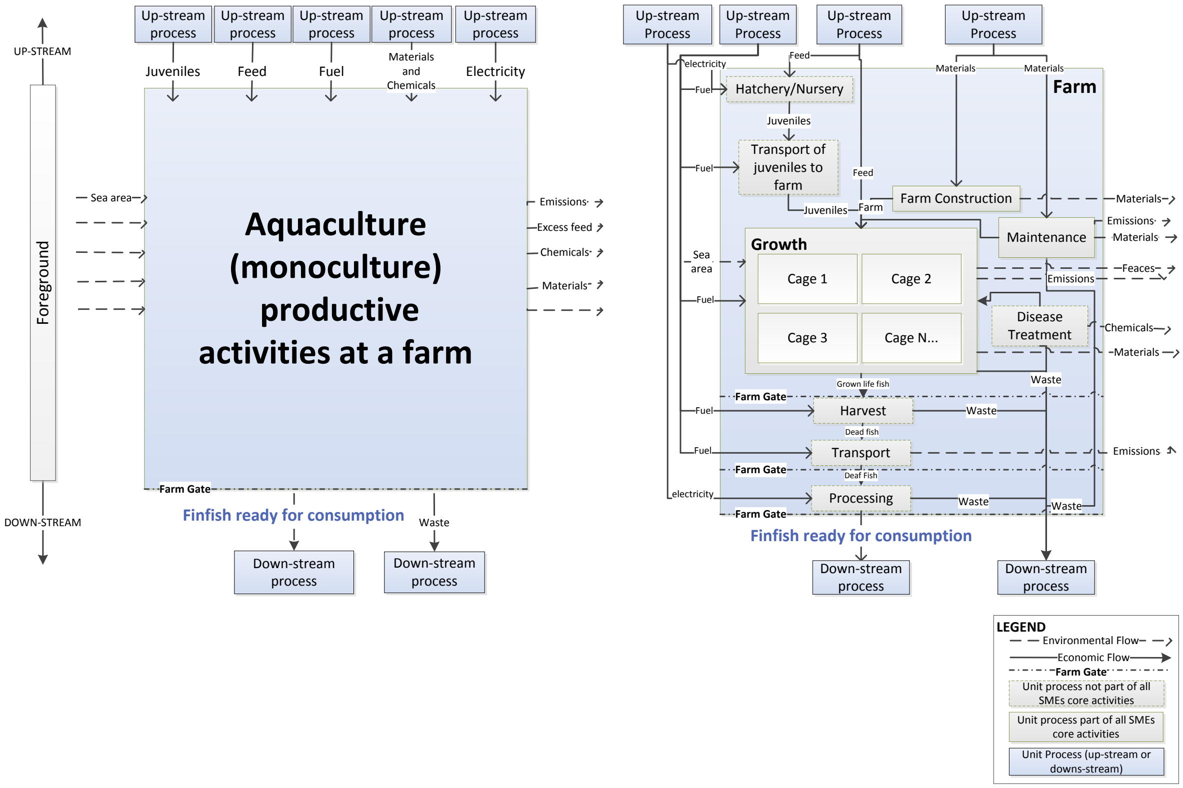

Figure 1. Left: "Black Box" aggregated and Right: Detailed disaggregated description of aquaculture farms

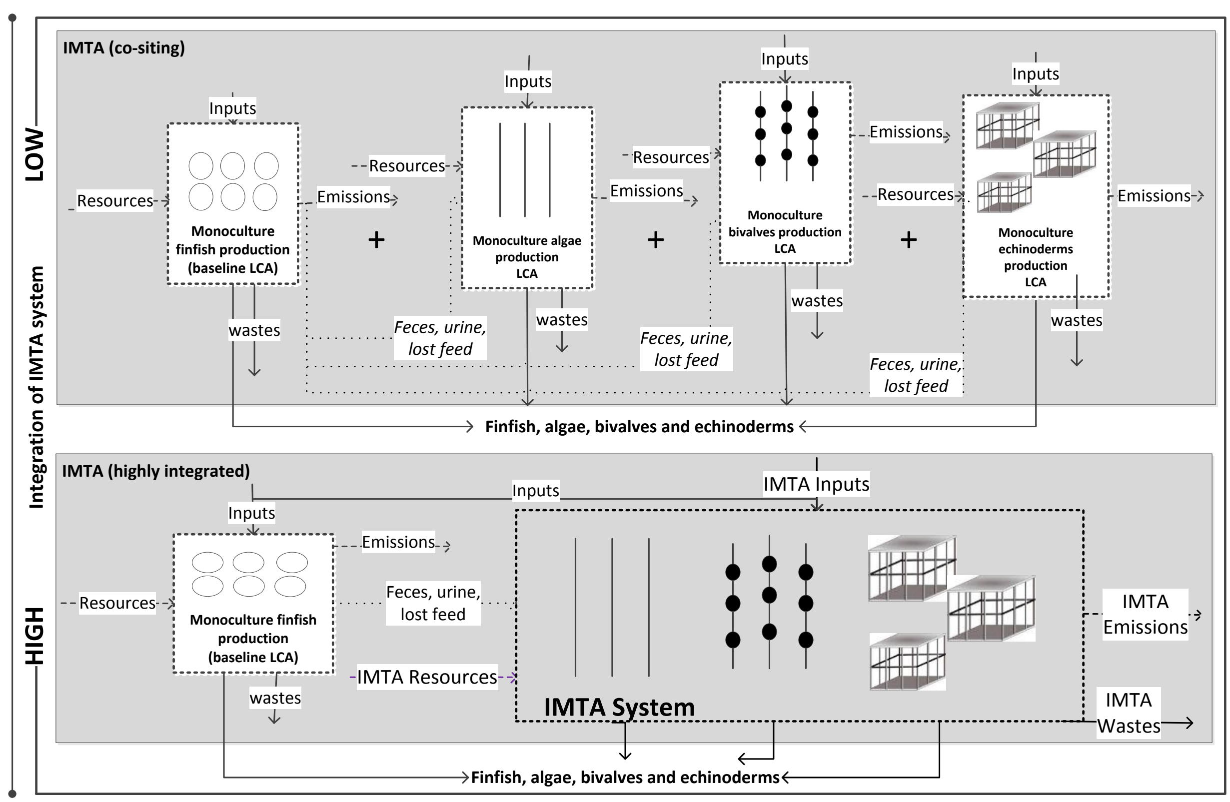

Figure 2. Level of integration of IMTA systems into the current production

On one side the IMTA system consists of a small add-on infrastructure and the operating activities (feeding, harvesting and related transport) are *highly integrated* into the current productive activities of the monoculture. In this case the IMTA system can be considered as highly integrated into the monoculture production system, and we refer to this extreme as the highly integrated type of IMTA.

On the other side the IMTA system corresponds to a relatively larger add-on infrastructure at sea constituting completely separate monoculture production lines for each co-cultured species, with its own inputs, resources, emissions and waste production. The latter extreme follows the description of IMTA by (Reid et al., 2009): "*Integrated aquaculture allows intensive management of several monocultures from different trophic levels within the same system, all connected by nutrient transfer through water"*. We refer to this extreme as the *co-siting* (or i*ndustrial symbiosis*) type of IMTA. We considered this extreme as *the low integration* extreme as only nutrient exchange in the water relates the different monocultures for the IMTA species.

Figure 2 represents schematically the two extreme levels of integration distinguished above: the upper part represents the lowest level of integration or co-siting (or industrial symbiosis) type of IMTA, the bottom part represents the highest level of integration.

Based on the descriptions of monoculture and IMTA systems, we now present our first conceptual and qualitative results addressing the relation between questions posed, type of analysis needed and levels of integration achieved in IMTA. These conceptual results consist of the scoping framework we intent to use further in the project once quantitative data becomes available for both monoculture and IMTA systems, in order to answer questions about the sustainability of IMTA as an environmental management concept that can minimize the environmental impacts of conventional monoculture aquaculture farms.

3. Results

In the methodology, we described how the monoculture and IMTA systems were qualitatively described by the pairings. Data to complete full attributional LCAs of the monoculture systems, are under collection by the parings and the IMTA systems are currently under pilot testing and are expected to achieve different levels of integration within the monoculture production activities and infrastructure. LCA will be used to answer two questions related to these systems: 1) what are the environmental trade-offs for SMEs considering to move from monoculture aquaculture practice towards IMTA (Q1: SME perspective); and 2) How do the environmental performance of IMTA species compare with their monoculture conventional alternatives (Q2: Product perspective).

Since the question determines the appropriate analysis and not the other way around, we present here the relation between these two questions, the type of analysis we will apply and the levels of integration achieved in IMTA systems. . We do so in order to determine the environmental trade-offs between the two systems that depend basically of three parameters: (1) the produce i.e. IMTA systems produce new co-cultured species next to finfish, (2) the nutrient discharge in the sea water due to lost feed and fish urine and feces, and (3) the life cycle impacts of the IMTA infrastructure e.g. upstream processes to produce inputs required to build and run the production of co-cultured species.

The flow diagram in Figure 3 shows the scoping framework for both Q1 and Q2. Q1 is a question from a company-perspective primarily, and is the main question for IDREEM. Companies are interested in increasing their eco-efficiency by cultivating economic species that grow on the nutrient discharge from the monoculture. This question is mainly addressed by a difference analysis which compares the environmental performance of the before and after IMTA system, taking into account differences in produce. In a difference analysis (Guinée et al., 2002) parts of the life cycle of the compared systems are expected to be quantitatively and qualitatively identical and are therefore omitted from the analysis to simplify it. The difference analysis can be performed for both extremes of integration and is thus independent of the level of integration as shown in Figure 3. However, the level of integration determines the magnitude of the trade-offs as in a low integration IMTA system the life cycle impacts of the IMTA infrastructure is expected to increase while in the high integration is expected to increase or perhaps decrease if inputs for the monoculture production are also used in the production of IMTA co-cultured species.

Moreover, full single-species LCAs can also be used to answer Q1. In this case, full attributional LCAs would be quantified for each monoculture species for all the co-cultured species in the IMTA systems and compared with the performance of the IMTA systems. Nonetheless, this would imply a change in the perspective for the question asked about the systems. In fact, we consider that full single-species LCAs leads to answer Q2, a question from a product-perspective, primarily comparing two ways of producing the same products (e.g., finfish, echinoderms, bivalves, algae, …): integrated in an IMTA system or by separate monoculture systems. In this case we will need to draft full single-species LCAs for each of the co-cultured species and compare these to the IMTA production of the same combination of species.

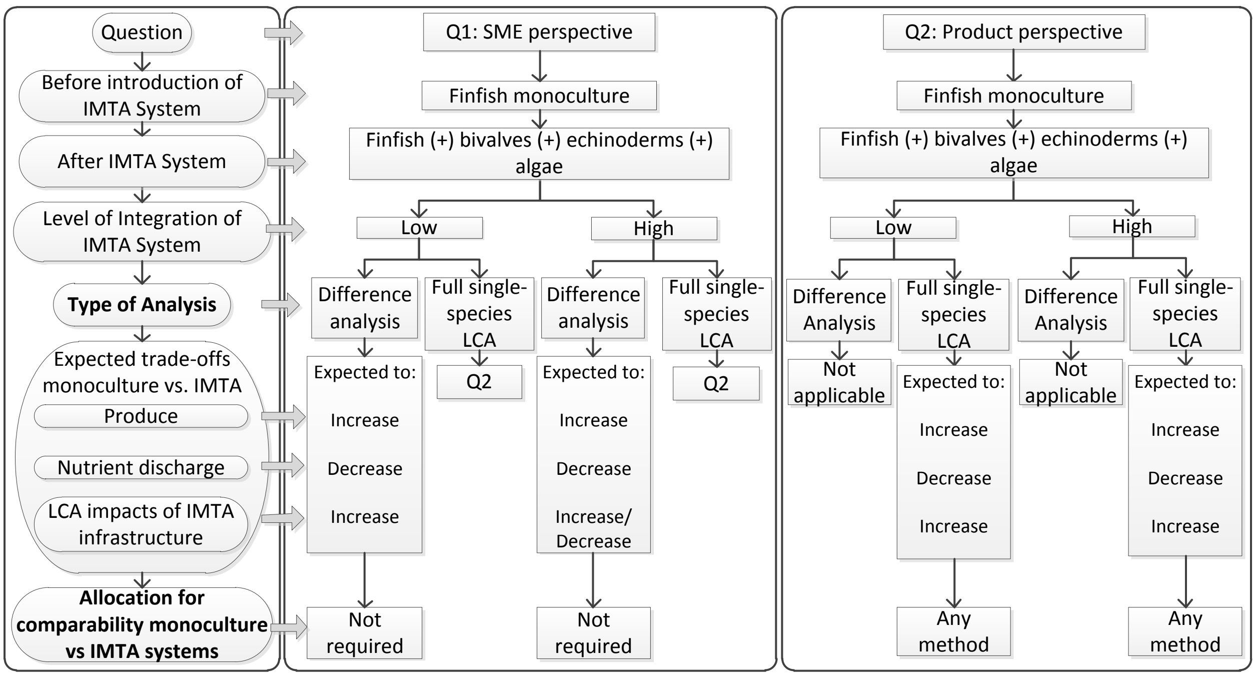

Figure 3. Scoping the IMTA systems LCAs starting from the question asked

The IDREEM SMEs currently produce only one species in their monoculture systems; as a consequence, we don’t have a complete set of representative monoculture systems to compare the IMTA with. We will thus have to adopt existing LCA studies on these co-cultured species, adapt them to the SME conditions where possible, and take their results as second-best baseline system. The choice for separate, full single-species LCAs is again independent of the level of integration, but the more integrated the more challenging the allocation issues for the LCAs performed will become. To make the before and after IMTA systems comparable allocations is therefore required and any method, among which partitioning principles, substitution or system expansion should be applied. For Q2 we consider that difference analysis for any level of integration is not applicable as it would be very difficult to identify the equal parts of the before and after IMTA systems, and therefore full single-species LCAs would be the appropriate way to analyze such question.

4. Discussion

Our preliminary conceptual results show how questions determine the type of analysis to be applied. More particularly, the questions determine the scope of the LCAs to be performed, being a difference analysis omitting large parts of the systems compared or being a set of single, full LCAs for each species cultured. Focusing on the two starting question formulated different types of analysis can be used in order to calculate the life cycle environmental impacts of the IMTA systems implemented in the IDREEM project. The conceptual results also show that the type of analysis is independent of the level of integration of new species into the current monoculture system. Nevertheless, the level of integration of the productive activities of the co-cultured species (e.g., bivalves, echinoderms and algae) into the existing finfish monoculture system is expected to determine the magnitude of the trade-offs. The LCAs to be performed and the IMTA systems proposed by the involved SMEs with hopefully differences in levels of integrations will determine whether this expectation is correct or not. A complicating issue then is that the IMTA systems developed and tested within the IDREEM project will most likely not be in a stage beyond pilot-scale. This will be challenging for the LCA work as it implies that the LCAs can only deal with the pilot-scale on a more or less empirical data level. We will have to apply scenario and up-scaling techniques to estimate the LCA results for a full commercial exploitation of the IMTA plans.

5. Conclusion

IMTA is regarded as an environmental management concept that can minimize the environmental impacts of conventional monoculture aquaculture farms while expanding their economic base (Price & Morris, 2013). These characteristics of IMTA systems hold as long as 1) there are no significant trade-offs between the discharge reduction and the life cycle environmental impacts of the IMTA system and 2) the species to be used in the IMTA system are potentially commercial species produced at scales that yield sufficient additional profit.

In this paper we explored the relations between questions asked, levels of integration foreseen for the IMTA systems and the type of analysis to be performed to evaluate the environmental trade-offs between monoculture and IMTA systems, particularly those part of the EU FP7 IDREEM project. Our preliminary conceptual results show a scoping framework with some of the expected trade-offs and also shows that although the type of analysis to be used is independent of the level of integration of new species into the current monoculture system, the magnitude of the environmental trade-offs between the discharge reduction and the life cycle environmental impacts of the IMTA system can depend on the level of integration.

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