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Dynamic simulation based method for the reduction of complexity in design and control of Recirculating Aquaculture Systems

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A B S T R A C T

In this work we introduce the "Extensible Fish-tank Volume Model" that can reduce the complexity in the design and control of the Recirculating Aquaculture Systems. In the developed model we adjust the volume of a single fish-tank to the prescribed values of stocking density, by controlling the necessary volume in each time step. Having developed an advantageous feeding, water exchange and oxygen supply strategy, as well as considering a compromise scheduling for the fingerling input and product fish output, we divide the volume vs. time function into equidistant parts and calculate the average volumes for these parts. Comparing these average values with the volumes of available tanks, we can plan the appropriate grades. The elaborated method is a good example for a case, where computational modeling is used to simulate a "fictitious process model" that cannot be feasibly realized in the practice, but can simplify and accelerate the design and planning of real world processes by reducing the complexity.

1. Introduction

Global need for the quantitatively and qualitatively secure fish products requires the fast development of Recirculating Aquaculture Systems (RAS). These complex production systems have an increasing role, providing healthy food for the growing population [1]. In addition to its health promoting and poverty reducing capacity, aquaculture sector has a significant role in creating jobs and livelihood for hundreds of millions of the population, worldwide.

According to the up-to-date statistics in the report on The State of World Fisheries and Aquaculture [2], Asia produces more than 88% of the total aquaculture production in the world, while almost 70% of this Asian production comes from China. Europe, with its 4.3%, obviously needs to enhance its performance in this sector. European Aquaculture Technology and Innovation Platform were founded to cover the diverse range of challenges in the field, and set out a strategic agenda [3]. However, effective and promising execution implies the involvement of Asian, especially Chinese collaboration to the work program. On the other hand, the fast development of Eastern countries has to be accompanied by the highest standards of environmental protection.

Main driver of research in this field is that the population's increasing demand for fish and seafood products exploited the natural resources of oceans. Considering the increasing need for sustainable intensification of aquaculture systems, recycling aquaculture systems (RAS) came to the front in

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the past decades. These systems, supplemented by advanced tools and methodologies, as well as running under controlled conditions, with almost closed water recycling loops, are designed to provide the appropriate amount and high quality fish- and seafood products, with the possible minimal load on environment. Several papers focus on the design and optimal performance of these systems (e.g. [4]). Recent technological advancements make possible the deployment of modern methods for detection and control of aquaculture systems in various aspects (e.g. [5,6]).

Aquaculture sector competes highly on the natural resources (water, land, energy, etc.) with the other resource users. Considering this, the development of the sustainable and profitable aquaculture systems must work with considerably decreased fresh water supply, that needs the application of sophisticated design, decision supporting and control tools. Accordingly, dynamic modeling and simulation supported design and operation of RAS are in the focus of research and development.

RASs are artificially controlled isolated systems that need maximal recycling of purified water with minimal decontaminated emissions. Also, these isolated systems need disinfected water supply from the environment. Accordingly these process systems integrate animal breeding with complex bioengineering and other process units in a feedback loop. In addition the fish production has to be solved in a stepwise, multistage process, which is also coupled with the characteristics of the life processes (e.g. with the differentiation in growth).

The main challenge in this field is to increase its capacity and to ensure its sustainability in the environment, at the same time. In addition it is highly affected by the long term climate change, as well as by the more frequent extreme weather situations. This can be managed only by the utilization of advanced information technologies for design, planning and control of aquaculture systems.

Advanced Information Technology has been developing more and more powerful hardware and software tools for global communication to share the accumulated data and knowledge, as well as for optimal design and control of complex systems. Formerly these results were utilized mainly by the industrial and service sectors. However, in the forthcoming period life sciences and applied life sciences (including agriculture, aquaculture, food, forestry, freshwater and waste management, as well as low carbon energy sectors) must have a pioneering role in going ahead, assisted by the newest results of Advanced Information Technology.

One of the challenging possibilities of computational modeling is that we can simulate also “fictitious processes” that cannot be feasibly realized in the practice, however the use of these models can simplify and accelerate the design and planning of real world processes by reducing the complexity in the early phase of problem solving.

It is worth mentioning that the rapidly evolving biosystems based engineering technologies have the advantage of last arrival in the application of up-to-date results of Information Technology. It means that the implementation of new methodologies can be cheaper and more effective if it starts in a “green field". Moreover the new technologies can be developed in parallel with the development of IT methods and tools.

The obvious gap between the (applied) life sciences and informational technologies has to be bridged by new modeling methodologies of process engineering, which evolve fast, motivated also by the above situation.

Computational modeling and simulation can definitely contribute to the effectiveness of aquaculture systems. Especially, complex RAS requires the simulation model based design and operation; consequently it became an active research field in the past years (e.g. [7,8]). There is a fast development also in model based understanding and control of net cage aquaculture processes (e.g. [9]).

The applied modeling methodologies vary in a broad range, from EXCEL spreadsheet calculations [10] to the sophisticated fish growth and evacuation model, combined with a detailed Waste Water Treatment (WWT) model in an integrated dynamic simulation model [8].

In the intensive tanks of the recycling systems the various nutrients, supplied with feed, are converted into valuable product. Considering the sound material balance of the system, many papers focus on the nutrient conversion and on material discharge [11,12]. Supply chain planning and management of aquaculture products is also a challenging question in the field [13,14]. Several research papers deal with the two-way interaction of aquaculture with environment, in general [15–17]; or focusing on actual fields of this interaction [18,19]. Up-to-date research works call the attention also to the importance of knowledge transfer and exchange of experience between field experts and policy makers. Also the importance of well established and conscious regulations (e.g. [20,21]) is emphasized.

The complexity in design and control of RAS comes from the fact that the prescribed stocking density needs a fast increasing volume of the subsequent stages, while the concentrations, determining growth of fishes, as well as waste production depend on the volume of the fish-tanks. As a consequence, the optimal feeding, grading, water exchange and oxygen supply strategies cannot be determined by modeling of a single tank, rather it must be tested for the various possible system structures. There are many variants in planning and scheduling decisions, based on the available number of tank volumes. In addition there is an additional combinatorial complexity in design, where the volumes of the tanks for the subsequent grades are also to be optimized. In this paper we show, how a fictitious “Extensible Fish-tank Volume Model” can help to reduce the complexity in the design and control of the Recirculating Aquaculture Systems.

2. Objective and approach

In our previous work, we implemented and tested an example RAS model by the Direct Computer Mapping based modeling and simulation methodology [22]. Based on these previous results we tried to develop a model based complexity reducing method for the design and control of RAS. Complexity comes from the fact that the prescribed stocking density in RAS needs an increasing volume in the subsequent stages, while all of the concentrations, determining growth and