UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF AN INTEGRATED MODEL FOR SUSTAINABLE AQUACULTURE AND OPTIMIZATION OF FISH PRODUCTION IN RACEWAY SYSTEMS

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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DEDICATION

To My Lovely Family

To Human and Needs for Love, Peace, Spirituality and Sustainable Environment

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

DEVELOPMENT OF AN INTEGRATED MODEL FOR SUSTAINABLE AQUACULTURE AND OPTIMIZATION OF FISH PRODUCTION IN RACEWAY SYSTEMS

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October 2017

Chairman : Associate Professor Zelina Zaiton Ibrahim, PhD
Faculty : Environmental Studies

Sustainable aquaculture needs effective fish farm management to balance high yield production with low farm effluent, as well as consider changes in available water resources. The aim of this research is to develop a model to simulate fish growth, total farm production, and effluent load estimation for single and multiple stocking events. Modeling is in a spreadsheet format for the most common system of cold-water fish farming in Iran, that is, the raceway system. Model equations were based on the literature and currently available aquaculture models. In addition, new equations, based on mass-balance considerations, and modification of temperature for conditions of fish growth in above optimum temperatures conditions are proposed. Five main modules, that is, Environment, Individual Fish Weight, Water Quality Effluent, Farm, and Analysis, were developed to cover the main processes and parameters in a fish farm. Multiple-model inference was adopted for estimating fish growth. Water quality parameters included dissolved oxygen, total ammonia nitrogen and phosphorous. Effluent load was estimated based on dissolved oxygen depletion, feed requirement, phosphate and total ammonia nitrogen. Single and multi-stocking events as well as use of multiple species is possible in the model. The model was validated to primary and secondary data. Primary data of water temperature and fish weight was used to validate the fish growth in the Individual Fish Weight module. Secondary data from published data sets and results from other current aquaculture models were used to compare with the simulation results of the model developed. The data were for trout, salmon and Seabream fish. The results for fish growth showed very good correlation (R^2>0.98) with the measured data of a fish farm at Haraz River, Iran, with mean absolute percentage error (MAPE) of less than 10 percent. Comparison of the model simulation results with other existing models, such as AquaOptima and AquaFarm, also showed very good correlations (R^2>0.98) except for estimation of feed requirements with the AquaFarm model results (R^2=0.87 and MAPE=24%). In conclusion, the model

developed produced several important results which contribute to improved knowledge for aquaculture modeling. These are the ability to use of a simple tool for complex situations, improved fish growth modeling, proposal for a parameterization of fish growth in temperature conditions which are beyond optimum growth temperature, the possibility to simulate for variable temperature patterns, together with the possibility for fish farm effluent estimation, under single and multiple stocking conditions. The model can be used for planning aquaculture development due to the capability for simulation of multiple scenarios in single integrated aquaculture model. In this way the model will be useful for a wide range of stakeholders as a tool for sustainable management of an aquaculture farm.

Abstrakt tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN MODEL BERSEPADU UNTUK AKUAKULTUR MAPAN DAN PENGOPTIMUM HASIL TERNAKAN DALAM SISTEM PALUNG

Oleh

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Akuakultur yang mapan memerlukan pengurusan ladang ikan yang berkesan untuk mengimbangi pengeluaran hasil yang tinggi dengan efluen ladang yang rendah, serta mempertimbangkan perubahan sumber air yang sedia ada. Tujuan penyelidikan ini adalah untuk membangunkan satu model untuk mensimulasikan pertumbuhan ikan, jumlah pengeluaran ladang, dan anggaran beban efluen bagi pengunaan stok tunggal dan berbilang. Pemodelan dilakukan dalam format hamparan untuk sistem penternakan ikan air sejuk yang paling umum di Iran, iaitu, sistem aliran palung. Persamaan model berdasarkan literatur dan model akuakultur yang sedia ada sekarang. Di samping itu, persamaan baharu, berdasarkan pertimbangan imbangan jisim, dan pengubahsuaian suhu bagi keadaan pertumbuhan ikan di dalam keadaan yang melebehi suhu optimum adalah dicadangkan. Lima modul utama, ia itu, Persekitaran, Berat Ikan Individu, Efluen Kualiti Air, Ladang, dan Analisis, telah dibangunkan untuk merangkumi proses dan parameter utama dalam ladang ikan. Inferens pelbagai model telah digunakan untuk menganggar pertumbuhan ikan. Parameter kualiti air termasuk oksigen terlarut, jumlah ammonia nitrogen dan fosforus. Beban efluen dianggarkan berdasarkan pengurangan oksigen terlarut, keperluan makanan, fosfat dan jumlah amonia nitrogen. Pengunaan stok tunggal dan berbilang serta penggunaan pelbagai spesies boleh dilakukan dalam model. Model ini telah disahkan kepada data primer dan sekunder. Data primer suhu air dan berat ikan digunakan untuk mengesahkan pertumbuhan ikan dalam modul Berat Ikan Individu. Data sekunder dari set data yang diterbitkan dan hasil daripada model akuakultur semasa yang lain digunakan untuk dibanding dengan hasil simulasi model yang dibangunkan. Data ini adalah untuk ikan trout, ikan salmon dan Seabream. Keputusan untuk pertumbuhan ikan menunjukkan korelasi yang sangat baik (R^2> 0.98) dengan data yang ukur dari ladang ikan di Sungai Haraz, Iran, dengan peratusan purata ralat mutlak (MAPE) kurang daripada 10 peratus. Perbandingan hasil simulasi model dengan model sedia ada yang lain, seperti AquaOptima dan AquaFarm, juga menunjukkan korelasi yang

sangat baik (R^2> 0.98) kecuali untuk anggaran keperluan bahan makanan dengan hasil model AquaFarm (R^2 = 0.87 dan MAPE = 24%). Sebagai kesimpulan, model yang dibangunkan menghasilkan beberapa hasil penting yang menyumbang kepada penambahan pengetahuan untuk pemodelan akuakultur. Ini adalah keupayaan untuk penggunaan perkakas mudah untuk situasi kompleks, pemodelan pertumbuhan ikan yang lebih baik, cadangan untuk parameterisasi pertumbuhan ikan dalam keadaan suhu yang melebihi suhu pertumbuhan yang optimum, kemungkinan untuk mensimulasikan untuk corak suhu berubah-ubah, bersama dengan kebolehan untuk melakukan anggaran efluen ladang ikan, di bawah keadaan stok tunggal dan berbilang. Model ini boleh digunakan untuk perancangan pembangunan akuakultur kerana kemampuan untuk melakukan simulasi pelbagai senario dengan menggunkan model akuakultur bersepadu tunggal. Dengan cara ini model ini akan berguna untuk pelbagai pihak yang berkepentingan sebagai alat untuk pengurusan mapan ladang akuakultur.

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I certify that a Thesis Examination Committee has met on 9 October 2017 to conduct the final examination of Mohammad Gholizadeh on his thesis entitled "Development of an Integrated Model for Sustainable Aquaculture and Optimization of Fish Production in Raceway Systems" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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I hereby confirm that:

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
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LIST OF ABBREVIATIONS

BIO	Biomass
BIOE	Bioenergetics Function
BOD	Biochemical Oxygen Demand
CAGR	Constant Absolute Weight Growth Rate
CSGR	Constant Special Weight Growth Rate
DGC	Daily Growth Coefficient
DGR	Daily Growth Rate
DSGR	Double-Logarithmic Specific Growth Rate
DO	Dissolved oxygen
DOCC	Dissolved oxygen carrying capacity
ELV	Water Resource Elevation
EPA	Environmental Protect Agency
FCE	Feed Conversion Efficiency
FCR	Food Conversion Ratio
Feed	Daily Feed Ration (ton)
FFI	Fish Feeding Index
FGI	Fish Growth Index
FMR	Fish Metabolic Rate
FTS	Flow Through System
FR	Feed Rate
Fw	Feed waste
Feed G	Absorbed Phosphorous
GCM	Growth Curve Modeling

GRP	Growth Rate Potential
GDD	Growing Degree-Days
IFG	Individual Fish Growth
IFW	Individual Fish Weight (g)
LCA	Life Cycle Assessment
LWR	Length-Weight Relationship
NEL	No-Effect Limit
NH_3	Ammonia
NPU	Net Protein Unit
NSF_t	Count of Survived Fish at each Time step
pK_a	acidity constant
PP	Particulate Phosphorous ($kg.day^{-1}$)
PRAS	Partition Recirculating Aquaculture System
RAS	Recirculating Aquaculture System
SA	Sensitivity Analysis
SA-OFAT	Sensitivity Analysis One factor at the time
SGR	Specific Growth Rate
SS	Suspended Solid
TSS	Total Suspended Solid
TAN	Total Ammonia Nitrogen (kg/day)
TDL	Total Daily Load of each water quality parameter
TGC	Thermal-unit Growth Coefficient
TP	Total Phosphorous ($kg.day^{-1}$)
VBA	Visual Basic VBA Application
VBGF	Von Bertalanffy growth function

CHAPTER 1

INTRODUCTION

1.1 Background

Aquaculture fish farming is one of main sources of food. Aquaculture production with a yearly average rate of 9% is one of world's fastest growing industries (Timmons & Ebeling, 2012). Every decade aquaculture production has doubled (Fitwi,et al., 2012). Technological advances have led to these growth (Kumar & Engle, 2016). Aquaculture now provides almost half of all fish for human consumption (FAO, 2016). Fish farmers need to have a good production plan and high health fish (Ghorbani & Mirakabad, 2010). This includes high yield production and high income with less inputs of resources. However, it is evident that water quantity and quality are one of the main resources in a fish farm. Water sources are limited in many countries; however the fish farmers need to have higher production even if they cannot increase their water resource. Farmers and fisheries try to have high production even in dry seasons. The effluents of fish farms will negatively impact on water quality parameters (Kohanestani, et al., 2013). On the other hand, the water authority approach, such as in Iran (Torabi, 2010), is to decrease water demand and effluent discharge. For sustainable aquaculture, there needs to be a good approach for farm production management. There should be a balance between higher yield production, for higher income, but with less farm effluent to the environment.

A fish production plan may be achieved experimentally, manually, or mathematically, by modeling, for instance, the pollutant load or changes in water quality. These can achieved by computing the carrying capacity of the water resources and the maximum amount of fish that can be reared in the farms. Nowadays, computer software, such as spreadsheet programs and mathematics used as common tools in a modeling of fish production. For instance, scientists and aquaculture farmers have to consider aquaculture effluent impact on receiving waters. They can apply computer programs for water quantity and quality, water availability and water temperature (Handisyde, Ross, & Allison, 2006) .

1.2 Problem Statement

Salmonidaes are one of the most important cold water cultured fishes in the world. In Iran, farming of this species started in 1960. Now, Iran is one of the important Salmonidaes producers in the world (Adeli, & Baghaei, 2013), especially trout fish. The improvement of the aquaculture production plans is important for the Iranian Government because of the local potential for the aquaculture, and the high request by the consumer (Adeli, & Shabanpour, 2007).

Between 2005 through 2010 the issues about aquaculture sustainability, the need of fish farmers and production management modeling, related to the ecology and environment, was discussed informally with key persons and experts in Iran, as listed in Table 1.1. These discussions were made during aquaculture and environment conferences and in the offices of the mentioned experts. From these discussions the main points raised were:

- The need for the aquaculture sustainability approach;
- The need of modeling in trout farm management on flow though system in Iran;
- Modeling of the yield and carrying capacity of springs and rivers with fluctuations in water flow and temperature;
- Modeling of the effluent of fish farms; and
- Modeling for fish farm management based on multi-stocking and multi species for scenario planning.

A recent FAO study report (Hasan, 2013) also identified the need to optimize feed production and on-farm feed management practices in aquaculture. The FAO (2016) stated that the "implications of feed type, formulation and feed management practices on the environmental footprint and economics of the farming operation are important issues that farmers need to consider when planning their activities". They also recommended that there must be simple tools for the farmer to monitor farm production indices such as feed conversion efficiency and growth rate.

Table 1.1 : Experts consulted on aquaculture issues in Iran between 2005 and 2010

No.	Title	Last Name	First Name	Position (in 2017)
1	Engr.	Aryannejad	Mohsen	Director, Cold Water Group, IFO
2	Engr.	Bahmanyary	Hussein	Ex Director, Bushehr Providence, IFO
3	Engr.	Esmaeyly	Mohammad Ebrahim	President, Abzian Asia Aquaculture Consultant Co.
4	Engr.	Hassani	Mohammad Reza	Manager, Peyab Novin Aquaculture Consultant Engineers.
5	Dr.	Hosseinzadeh Sahaf	Homayun	Director, Aquaculture Department, IFRO
6	Engr.	Jedi Rangraz	Mohammad	Ex Director, Tehran Providence, IFO
7	Engr.	Jamalzadeh Fallah	Faryborz	Ex Director, Coastline Office, Iran Department of Environment
8	Dr.	kakolaki	Shahpour	Director, Capture Fisheries, IFO
9	Engr.	Mokarami	Ghobad	Aquaculture Experts in IFO
10	Dr.	Nabizadeh	Arash	Iran Aquaculture Association
11	Engr.	Norbakhsh	Ali Reza	Ex Director, Aquacultural Engineering Department, IFO
12	Dr .	Partabyan	Massod	Trout Farmer; Best Iranian Trout Famer in 2003
13	Dr.	Pirali	Ali	Director, Charmahal Providence Technology Park
14	Dr.	Pourgholam	Reza	Ex Head, Caspian Research Center, IFRO
15	Assoc Prof.	Rafiee	Reza	Head, Fisheries Department, Tehran University
16	Engr.	Roshanro	Ahmad	Aquaculture Experts in Azarbayjan Providence, IFO
17	Dr.	Salehi	Hassan	Iran Agriculture Deputy Minister; President, IFO
18	Dr.	Shakouri	Mehdi	Ex. Director, Aquaculture Department, IFO
19	Dr.	Sharifpour	Issa	Aquatic Health Expert in IFRO
20	Prof.	Soltani	Mehdi	Ex Head, Fish Health Department, Tehran University
21	Dr.	Torabi	Sedigheh	Head, Water Allocation Group, Ministry of Water and Power
22	Dr.	Yazdani Jahromi	Yazdani Jahromi	Private Sector Aquaculture Consultant
23	Engr.	Zolfaghari	Karim	Director, Agriculture Department, Tehran Province
24	Dr.	Zorrieh Zahara	Seyed Ebrahim Jalail	Head, Aquatic Health, IFRO

Note: IFO - Iranian Fisheries Organization ; IFRO - Iranian Fisheries Research Organization

Aquatic health experts also believe that a fish simulation model for water quality monitoring helps to prevent fish disease risk and there are several models of fish growth and effluent, and of aquaculture production simulation. For instance, there is POND DSS (Bolte, Nath, & Ernst, 2000), AquaFarm (Ernst et al., 2000), RTDSS (Wang & Song, 2006) and multiple stock spreadsheet model by Colt, Schuur, Cryer, & Miles (2009).

Colt et al. (2009a) calculated carry capacity by developing a computer program in using FORTRAN language. Ernst, Bolte, & Nath (2000) developed computer software to simulate the operation and facility of the fish farm. Wang & Song (2006) simulated raceway trout farm by using spreadsheet software. Colt et al. (2009b) also applied spreadsheet software to study salmon hatchery planning. All of them reported good results in case of using a computer program as a tool. By introducing carrying capacity models for aquaculture development model the environmental impact effects can be reduced (Ross et al., 2013; White, Phillips, & Beveridge, 2013).

From the literature on aquaculture fish farm models, as mentioned above and presented in Chapter 2, there are some gaps that were identified. Currently, all of the above studies and models are for constant temperature condition. In the AquaOptima, (2006) model, any fluctuation of temperature is needed to be carried out manually. Previous models are for a single stocking and single a species. None include options for multi-stocking and multi-species condition. Several of the experts in Table 1. 1, that is Dr. Nabizadeh from Iran Aquaculture Association, Prof. Soltani, Ex-Head of the Fish Health Department, Tehran University, and Dr Zorrieh Zahara, Head of the Aquatic Health, Iranian Fisheries Research Organization suggested that that this type of simulation model for multi-stocking and multi-species can be useful. Jamalzadeh-Fallah, former Director of the Coastline Office, Iran Department of Environment, also supported that a model for multi-stocking for assessing fish farm impact on the environment is still needed for sustainability assessment. A study carried on recirculating aquaculture system (Kumar & Engle, 214) concluded that feeding and stocking strategies can affect the farm profits made. The recent paper by Valenti et al. (2018) on aquaculture sustainability also stress the environmental parameters of natural resource use and effluents from farms.

A recent review by (Anyadike, et al., 2017) of aquaculture production models found that none of the existing model could be used to model the effects of different management scenario or consider the fish species that they were interested in. They made the conclusion that there was a serious need to develop models that can predict the effects of environment on the performance of fish species in order to help the farmers for different management scenarios.

Currently, there are no models that can run an integrated simulation of fish growth, farm production, and effluent resulting from multi-stocking, multi-species and multi-growth farm condition, which is closer to the real condition for aquaculture farmers. This is also one of the points raised by the Iranian experts consulted. For stakeholders, such as fish farmer, environmental decision maker, fishery and environmental student and researcher, it is a gap in knowledge for promoting sustainable aquaculture.

1.3 Objectives

The aim of this research is to develop a model to simulate fish growth, total farm production, and effluent load estimation for single and multiple stocking events. The focus is on the trout farms with flow-through systems (FTS). The specific objectives are, to:

1. Develop a model for FTS fish farm management by applying multiple-models for fish growth in a spreadsheet format;
2. Develop a simulation model for effluent load estimation from an FTS fish farm; and to
3. Integrate the simulation of fish farm production management by incorporating effluent, multi-stocking and multi-species conditions.

1.4 Thesis Outline

The following chapter, Chapter 2, presents the review of the literature on fish growth, fish production simulation, and fish effluent modeling. Chapter 3 presents an overview of the methodology approach, and the framework for the development of an integrated aquaculture model for fish farm production and effluent simulation. Each module of the model includes the effective parameters, variables, functions, and procedures. The validation and calibration approach, dataset types, and implementation limitations are described in this chapter. In Chapter 4, the model validation results and comparison to similar models is discussed. In Chapter 5, the conclusion and achievements are presented.

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