Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/issn/15375110

Research Paper

A model for restocking and harvesting aquaculture: A case of multi-pond, multi-cycle, and multi-fish type farming

Kanokpatch Wonginyoo [a,1], *Kullapapruk Piewthongngam* [b,*], *Pachara Chatavithee* [b,2], *Jumpol Vorasayan* [c,3]

[a] *Graduate School, Khon Kaen University, 40002, Thailand*
[b] *E-saan Center of Business and Economic Research, Faculty of Economics, Khon Kaen University, Khon Kaen 40002, Thailand*
[c] *Faculty of Agro-Industry, Kasetsart University, Bangkok 10900, Thailand*

ARTICLE INFO

Article history:
Received 17 June 2017
Received in revised form
17 May 2018
Accepted 22 June 2018

Keywords:
Fish production plan
Mathematical model for aquaculture
Fish supply chain management

Aquaculture rotation problem is a continuous operation in which harvesting decision affects factors such as payoff, product size/growth and the growing of a new crop. To maximise the overall returns, a manager must balance the returns from a new crop after harvesting the current one. The situation is more complicated when dealing with large numbers of small-scale farmers and year-round demands in crop variation from month to month. In this study, a mathematical model and a heuristic based on the genetic algorithm (GA) for multiple ponds, multiple fish types, and multiple cycles for restocking and harvesting decision, with the objective of profit maximisation, are developed. A scheduling and restocking plan demonstrates the simplicity and ease in facilitating the decision.

1. Introduction

An optimised scheduling for commercial aquaculture has been demonstrated to improve both the productivity (Yu & Leung, 2005) and profitability (Yu, Leung, & Bienfang, 2006) of a commercial aquaculture farm. A commercial aquaculture operation produces fisheries all year round, hence managers must decide the time for harvesting and restocking. Though the decisions are common, they involve several types of disparate information, which are not easily/optimally processed. Clearly, a new crop cannot be stocked until the

* *Corresponding author*. Fax: +6643 202 267.
E-mail addresses: kanokpatch@webmail.npru.ac.th (K. Wonginyoo), pkullap@kku.ac.th (K. Piewthongngam), chatavithee@hotmail.com (P. Chatavithee), jumpol.v@ku.th (J. Vorasayan).
[1] Fax: +6643 202 267.
[2] Fax: +6643 202 267.
[3] Fax: +66 2562 5001.

https://doi.org/10.1016/j.biosystemseng.2018.06.019

previous one has been harvested; in light of this, to maximise the overall returns from several production cycles, the manager must balance the returns from retaining an existing crop with potential returns from a new crop after harvesting the current one. For multiple production units, synchronisation of harvesting decisions among production units also needs to be considered. Therefore, the determination of the optimal harvest schedule to maximise the overall return for a multiple pond (henceforth, multi-pond) and multiple cultivation cycle (henceforth, multi-cycle) setting is an extremely complex decision process (Yu et al., 2006). Yu and Leung (2005) were among the pioneers to incorporate the multi-cycle and multi-pond setting in an aquaculture crop rotation model. Later, their model was adapted by others (e.g., Yu et al., 2006; Yu & Leung, 2009). However, this model was developed based on one type of fish production, which is used for human consumption.

Unlike food fish, which primarily focuses on the total mass of fish produced, ornamental fish are sold by number and have to be of a minimum size to be accepted on the market (Olivier & Kaiser, 1997). Likewise, the ornamental fish price depends on its quality (size/length, colour, and shape) (Halachmi, 2006). Hence, as stated by Olivier and Kaiser (1997), the goal of ornamental fish production is the highest number of fish of a given size with consistently low size variation, within the shortest possible time. To optimise fish growth, past studies have focused on selection of culture systems (Olivier & Kaiser, 1997), stock density (Olivier & Kaiser, 1997; Stone & McNulty, 2003; Jha & Barat, 2005), feeding and feeding frequency (James & Sampath, 2004), rather than production scheduling. Though most of the studies on feeding ratio focus on optimum feeding at a certain market size, natural life cycle implies optimum profitability of fish culture at a certain fish age. Feeding fish beyond the optimum point does not necessarily yield more profit. For example, James and Sampath (2004) showed that after a certain age, the feed conversion ratio naturally and gradually drops. Likewise, Ortega-Salas, Cortés, and Reyes-Bustamante (2009) showed steady fish length at a certain age. Hence, when considering production scheduling to start and harvest fish production, price, cost, and profit of each fish stage is necessary.

To optimise profit of ornamental fish production, which is size/age-dependent, Halachmi (2006) proposed a simulation model for a year-round production plan that determines the optimal layout and management regime for ornamental fish, recirculating aquaculture systems by quantifying fish growth rate (to obtain fish length) and considering cost, price, and profit at different fish age. In Halachmi's work, Koi (*Cyprinus carpio*) was the case study. His case was not All-In–All-Out production, hence the model allows the rearing of one species with fish prices depending on length, colour, and shape, and that fish can be marketed, rejected, and continue growing in another tank depending on its marketability and profitability. Likewise, an aquaculture model stated earlier has also been developed for harvest scheduling and restocking of a single product (species). However, in the case of ornamental fish, where major producers located in tropical countries (e.g., Sri Lanka, Thailand, Malaysia, and Indonesia) are small-scale farmers, the farmers usually organise themselves in groups in order to satisfy year-round demands for different fish species (Table 1). Together with these demand variations, the price, cost, and profit of each varies according to the fish type and size (length), as indicated in Table 2. Determining fish size/length to produce will automatically determine fish production time/age. Hence, optimising farm profit while satisfying year-round demand for multi-pond, multi-cycle, and multi-fish type (i.e., multiple fish type) requires a consideration of these production times and price factors. Synchronising the harvesting and stocking plan with such problems is a complex task. Different production times, lack of

Table 1 – Quantity of Thai ornamental fish exports to United States of America (kg).

Month	Siamese fighting fish (*Beta splendens*)	Oscars (*Astonotus ocellatus*)	Koi carp (*Cyprinus carpio*)	Goldfish (*Carassius auratus*)
Jan-2015	5863	147	230	5
Feb-2015	4410	128	474	5
Mar-2015	4778	90	443	0
Apr-2015	4720	112	540	30
May-2015	3897	194	299	150
Jun-2015	3897	163	285	150
Jul-2015	4317	160	419	0
Aug-2015	4608	157	0	225
Sep-2015	3947	137	0	100
Oct-2015	4402	118	0	96
Nov-2015	3362	104	0	0
Dec-2015	3751	143	0	564
Jan-2016	5731	158	0	137
Feb-2016	3772	116	0	88
Mar-2016	4038	169	0	0
Apr-2016	5207	266	1000	0
May-2016	4102	135	980	0
Jun-2016	3745	125	0	0
Jul-2016	4792	140	0	0
Aug-2016	3645	193	0	0

Data are obtained from Thai Ministry of Commerce in October 2016.