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Prediction of water temperature in prawn cultures based on a mechanism model optimized by an improved artificial bee colony

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ABSTRACT

To reduce aquaculture risk and optimize water quality management in prawn culture ponds, this paper uses mechanistic and statistical analytic methods to propose a hybrid water temperature forecasting model based on the water temperature mechanism model (WTMM) with optimal parameters selected by an improved artificial bee colony (IABC) algorithm. Because of existing problems with using an artificial bee colony algorithm in modeling, an improved ABC with a dynamically adjusted inertia weight based on the fitness function value was implemented to improve local and global search abilities. Then, IABC was employed to adaptively search for the optimal combinatorial parameters needed in the WTMM model, which overcomes the blindness of and limits to parameter selection for the traditional WTMM model. We adopted an IABC-WTMM algorithm to construct a non-linear mechanical prediction model. The IABC-WTMM was tested and compared to other algorithms by applying it to the prediction of water temperature in prawn culture ponds. Experimental results show that the proposed IABC-WTMM could increase prediction accuracy and execute generalization performance better than the original water temperature mechanism model (O-WTMM) and back-propagation neural network (BP-NN), but was inferior to the standard LSSVR model. Overall, it is a suitable and effective method for predicting water temperature in intensive aquacultures.

1. Introduction

Water temperature is a key physical habitat determinant for intensive aquaculture, as many of the physical, chemical, and biological characteristics of aquaculture ponds are directly or indirectly affected by temperature (Liu et al., 2015). Most waterborne plant and animal life survives within a range of water temperatures; thus, water temperatures that are too high or too low will affect growth and metabolic activities or can even result in mass mortality of waterborne animal and plant life (Chen et al., 2011). Changes in the aquaculture pond thermal regime can significantly impact prawn distribution, growth, production, mortality, habitat use, chemical reactions, toxicity of ammonia, and community dynamics (Liu et al., 2013a,b,c; Chen et al., 2011; Souza et al., 2013). For example, as water temperature rises, pH and dissolved oxygen levels will decrease, ammonia nitrogen content and salinity levels will increase, and the balance among water quality factors will be seriously disrupted, and excessively high temperatures can result in the death of prawns, fish, sea cucumbers, shellfish, river crabs, etc. (Liu et al., 2016; Souza et al., 2013; Hernández et al., 2007). Therefore, accurately predicting water temperature not only provides a basis for water quality control and fishery management decisions that can minimize aquaculture risks and optimize treatment operations but also ensures the healthy and sustainable development of the aquaculture industry (Liu et al., 2016; Hernández et al., 2007; Liu et al., 2013a,b,c). The ability to accurately predict water temperature a half-hour or more ahead is a very important issue in intensive aquaculture (Xu and Liu, 2013; Huang et al., 2011).

To solve the problem of water temperature prediction, various models have been developed and used to predict water temperature. The major models of water temperature simulation and prediction generally fall into three categories: mechanism models, stochastic models and regression models. There are both advantages and shortcomings to specific water temperature models. Stochastic and regression models are based on statistical techniques where water temperature is related to relevant input parameters (e.g., wind velocity, solar radiation, air temperature,

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relative humidity, etc.). Examples of these models include those of Kamarianakis et al. (2016), Mashaly and Alazba (2016), Yu et al. (2016), Pantazi et al. (2016), Piotrowski et al. (2015), Adam et al. (2015), Sergio and Francesca (2014), Venkadesh et al. (2013), Grbić et al. (2013), Lins et al. (2013), Xu and Liu (2013), Liu and Chen (2012), Ortiz-García et al. (2012), Citakoglu (2015), Mohammadi et al. (2015). However, these prediction models have numerous drawbacks, which include not considering internal physical processes, locally optimal solutions, over-fitting and poor stability. In contrast, mechanism models are used to predict water temperatures using a mathematical representation of the underlying physics of heat exchange between the prawn ponds and the surrounding ecological environment, such as those used by Diao et al. (2015) and Benyahya et al. (2010). Mechanism models provide insight into the mechanism that drives the prawn pond water temperature, and they are the most efficient tools to research the prawn pond heat components. However, these mechanism models have some drawbacks, including a complex structures, great difficulties in parameter identification, time consumption, etc. Accurate determination of parameters plays an important role in water temperature simulation, performance evaluation, model structure design, and optimization control to make mechanism models more suitable for water temperature prediction in intensive aquaculture ponds. Therefore, parameter identification with the help of a capable optimization technique is necessary.

The search algorithms used to solve the parameter identification problem of mechanism models can be separated into two classes: traditional and metaheuristic search approaches (Bahrami et al., 2016; Sugandhi et al., 2015; Askarzadeh and Rezazadeh, 2013). In the traditional approach, the least square method and a modified non-linear least error squares estimation approach based on Newton's method have been widely applied. However, these traditional optimization techniques need convexity, continuity and differentiability conditions to be applicable and involve heavy computations, are sensitive to the initial solution, are time-consuming, and most often lead to local optimal solutions, especially for a problem with noise and some uncertainty factor (Liu et al., 2013a,b,c; Askarzadeh and Rezazadeh, 2013). Therefore, to overcome the deficiencies of traditional search approaches, it is necessary to research other advanced search technologies to improve the efficiency of parameter identification.

With the enormous advances in machine learning and artificial intelligence over the last few decades, modern metaheuristic approaches have been developed, such as simulated annealing algorithms (SA) (Bahrami et al., 2016; Yannibelli and Amandi, 2013), differential evolution algorithms (DE) (Onan et al., 2016; Venske et al., 2014), genetic algorithms (GA) (Sawyerr et al., 2014; Liu et al., 2013a,b,c), particle swarm optimization algorithms (PSO) (Sugandhi et al., 2015), and ant colony algorithm (AC) (Beltramo et al., 2016; Khan et al., 2014). Among these techniques, swarm intelligence is usually embedded with the characteristics of a feedback mechanism, randomness, and synergy to develop a powerful and efficient mechanism, and has become increasingly popular for parameter identification in different application areas (Bahrami et al., 2016; Onan et al., 2016; Sawyerr et al., 2014; Liu et al., 2013a,b,c; Sugandhi et al., 2015; Beltramo et al., 2016). Although these metaheuristic approaches obtain better results than traditional ones, they each have their limits. For example, because SA is a solo-searcher, its performance is not only sensitive to the starting point of the search, but there is no rigorous theoretical foundation for determining SA parameters, particularly the parameters of the cooling schedule, so overall the algorithm performance is affected. DE performance depends strongly on its parameters; unfortunately, the key difficulty in the use of a DE algorithm is that the choice of these parameters is based on empirical evidence and practical experience and could be influenced by artificial factors. GAs frequently find promising regions of search space quickly, but may encode complexity, premature convergence, random oscillations, slow convergence, and other drawbacks (Vitorino et al., 2015; Li et al., 2015). PSO is easy to implement and has fewer parameters to set. However, this algorithm is also flawed with certain shortcomings, such as the potential to easily lose the diversity of population and it may be influenced by premature convergence (Liu et al., 2013a,b,c). The ant colony algorithm has a powerful ability to search for better solutions, but has disadvantages such as easy immersion into stagnation, slow convergence speed, and long run times. The inability of the above algorithms to achieve a good balance between exploration and exploitation leads to premature convergence, getting trapped in a local optima, and stagnation. The non-linearity of water temperature characteristics requires a high-performance optimization technique.

The artificial bee colony (ABC) algorithm is a new, population-based, metaheuristic approach inspired by the intelligent foraging behavior of bee swarms and can be used to find optimal or near optimal solutions to numerical problems (Zorarpaci and Özel, 2016; Askarzadeh and Rezazadeh, 2013; Akay and Karaboga, 2012). It is a simple and robust optimization algorithm that can be easily implemented in widely used programming languages and has proven to be both very effective and quick for a diverse set of optimization problems. In comparison with SAs, DEs, GAs, PSOs, and ACs, the ABC algorithm is considered to be an excellent technique for solving combinatorial parameter identification problems because ABC possesses the capability to reinforce information sharing and exchange, memorization, escape from local optima, easy implementation, and adjustment of few parameters (Nseef and Abdullah, 2016; Askarzadeh and Rezazadeh, 2013). The ABC algorithm is a novel, intelligent computing research field and hotspot after PSOs and GAs, and research of the ABC algorithm has been the concern of many experts and professors (Zorarpaci and Özel, 2016; Tsai, 2014; Askarzadeh and Rezazadeh, 2013; Akay and Karaboga, 2012).

This paper proposes a new solution based on artificial bee colony algorithms to obtain the best possible series of parameter values for water temperature mechanism prediction models in prawn culture ponds. The validity of the predicted parameters is verified by comparing the predicted results with experimental results available in the literature. This paper is organized as follows: Section 2 describes the study area and sources of data, temperature mechanism prediction models and the improved artificial bee colony algorithm. Section 3 describes the procedure of parameter estimation based on IABC. A case study is described in Section 4. The results of the proposed method applied to the case study are presented in Section 5, followed by an accompanying discussion. Conclusions are drawn in Section 6.

2. Materials and methods

2.1. Study area and data source

The study area was the demonstration zone of the Xiangshan modern fishery, located in the Xiangshan district of Zhejiang Province, China. The fisheries lie between the latitudes of 28°51′N and 29°39′N and the longitudes of 121°34′E and 122°17′E, which is an area of approximately 133,333.33 m^2 (Fig. 1). The area faces the Pacific Ocean, forming a subtropical monsoon climate, four distinct seasons, and an annual average temperature of 16–17 °C.

2.2. Sampling and measurement

In this study, approximately 20 prawn culture ponds were selected for monitoring. Each experimental pond was