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Water quality assessment in shrimp culture using an analytical hierarchical process

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ABSTRACT

Water quality assessment is an important activity for controlling harmful crisis in aquaculture systems. The objective of our study was to develop a new Water Quality Index focused on monitoring of shrimp farms; detecting poor water quality and preventing negative effects in the ecosystem. Usually, several water quality parameters are monitored and measured in a shrimp farm during a farming period. Those parameters are classified according to their negative effects in the ecosystem and their respective allowed limits are also defined. The proposed Water Quality Index assigns a priority level to each water parameter through a new analytical hierarchical process (AHP), which allows an accurate assessment of the water quality. Our proposed index was applied to assess the water quality condition in extensive shrimp farms in Mexico. A comparison between our approach and those proposed in the literature shows its good performance when real environments are assessed.

1. Introduction

Aquatic organisms are susceptible to suffer stress when ecological conditions are not adequate. High stress levels generate low feeding and low growing rates; and promote the appearing of sickness in the organisms. A good water quality condition is essential for any aquaculture farming. Water quality affects reproduction, growth and survival of aquatic organisms. The criteria for good quality water assessment depend on the kind of organisms to be studied and are clearly established by safe levels. The ecosystem of a shrimp pond is composed by soil and water; the main factors affecting shrimp organisms are used as water quality parameters. However, the negative effects are reduced if ponds are monitored and controlled adequately, maintaining good water quality conditions (Boyd and Musin, 1992; Chien, 1992; Feliu et al., 2009).

A Water Quality Index (WQI) is a mathematical instrument used to transform large amounts of water quality data into a single number, which summarizes different water quality parameters to provide a whole interpretation of the behavior of the water quality parameters involved in shrimp culture (Simões et al., 2008; Ramesh et al., 2010). In the literature, several water quality indexes have been proposed; however, they only give a partial solution for this problem since the number of monitored water quality parameters is limited and they do not allow using them in a weighted way for water assessment (Ferreira et al., 2011; Cohen et al., 2005; Beltrame et al., 2004). Moreover, in the literature, we can also find techniques where several environmental quality indexes have been implemented based on artificial intelligence (Gharibi et al., 2012; Bishoi et al., 2009; Lermontov et al., 2009; Pedregal et al., 2009; Yañez et al., 2008; Wang et al., 2008; Salazar, 2007; Ocampo et al., 2006; Muttil and Chau, 2006; Li et al., 2006; Gutiérrez, 2004). These works have motivated the proposal presented in this paper for monitoring water quality parameters in shrimp culture, but assigning a priority level to each water parameter through a new analytical hierarchical process.

Additionally, international organizations have proposed some models for assessing water quality. Different criteria about good water quality practices, given by those international organizations, have been used as support of this type of work (ACA, 2010; NSF, 2010; CCME, 2010; SAGARPA, 2010). The Canadian Council Ministry of Environment (CCME, 2010) proposes a water quality model, which assesses water bodies based on statistical analyses, providing an index which has no limits about the number of parameters used. The National Sanitation Foundation (NSF, 2010) provides a Water Quality Index, which is used mainly for fresh water bodies. The Mexican Ministry of Environment, Natural Resources and Fisheries (SEMARNAP, 1996) provides a Water Quality Index based on statistical analysis. However, the CCME, NFS and other

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similar indexes have some weak points, for example some parameters involved in the index equations could dramatically influence the final score without any valid justification. However, the most critical drawback of this kind of indexes is that they cannot deal with water quality priorities in the sense that some parameters are more important than others for determining water quality condition.

Recently in Carbajal et al. (2011) and Carbajal-Hernández et al. (2012), new Water Quality Indexes were developed using fuzzy inference systems. In the first work, a water quality index (HWQI) was proposed using the most critical parameters (Beltrame et al., 2004; Hirono, 1992) in shrimp culture (temperature, dissolved oxygen, pH and salinity). This model also has been applied for water quality prediction using sample sets of different size. In the second work, a water quality model for immediate water quality assessment was developed. This model provides a whole interpretation of the water condition in an ecosystem giving a quick solution for water quality assessment. The use of subjectivity and uncertainty provided by a fuzzy inference system in water analysis, improves the assessment and crisis detection in shrimp ecosystems. However, the use of fuzzy inference is too complex. In this sense, the aim of this paper is to provide an accurate and easy to implement Water Quality Index, which can be adjusted depending on the requirements for a specific aquaculture system. Our hypothesis is that a correct and customizable assignment of priorities over a set of water quality parameters, penalizing those critical parameters that can disestablish an ecosystem, is enough for determining a potential crisis.

In our research, the proposed Water Quality Index is used for analyzing the ecosystem of Litopenaeus vannamei in shrimp farms of Sonora, México, where water quality parameters are assessed for evaluating the water quality condition.

The rest of this paper has been organized as follows: in Section 2, water quality parameters and their main characteristics in water assessment are explained. In Section 3, a new water quality index based on an analytical hierarchical process is proposed; we also give a numerical example for a better understanding of our proposal. Section 4 shows some experiments using real environments, where the proposed index is compared against other similar water quality indexes proposed in the literature and by international organizations; this section shows the performance and efficiency of our proposal. Finally, Section 5 provides our conclusions and future research directions.

2. Water quality parameters

A substance in the water that can cause harm to aquatic organisms is known as pollutant. Pollutants can be present in water as solid particles or gases. Pollutants are frequently monitored in order to avoid their negative effects in shrimp organisms (SEMARNAT, 2010; CCME, 2010). Water quality assessment is based on the results of toxicity tests. These tests measure the response of aquatic organisms to certain quantities of specific pollutants (Carbajal-Hernández et al., 2012; Páez, 2001; Chien, 1992). Different aquatic species have different tolerances for specific toxic compounds. When water quality parameters surpass those limits, the water quality condition is deteriorated; generating high stress levels in shrimp organisms.

Understanding ecological processes occurring in shrimp culture is useful to understand the disease issues faced by shrimp farmers. A bad water quality control increases shrimp stress level and compromises production, it also makes shrimp organisms more susceptible to diseases (Ferreira et al., 2011; Boyd, 2002).

The required water quality is determined by the type of organisms to be cultured. Since, physical, chemical and biological principles are usually taken as the basis of water quality assessment, in Section 2.1 we describe the water quality parameters used in this work for water quality assessment according to their monitoring frequency, as well as their importance in the shrimp ecosystem. In Section 2.2, optimal concentration levels of water quality parameters are given in order to understand the Water Quality Index proposed in this paper.

2.1. Water quality parameters importance

In most theoretical and experimental studies for assessing water quality, water quality parameters are monitored for detecting extreme negative situations focusing on critical values of these parameters (Ferreira et al., 2011; Simões et al., 2008; Beltrame et al., 2004; Hirono, 1992). Specifically, there are several difficulties in commercial shrimp farms for measuring water quality parameters like extremely hot weather; many and huge crop areas, high prices of new technologies, etc. Therefore, in practical situations, the analysis is commonly limited to measure a specific set of parameters, which are relevant for the ecosystem and relatively easy to measure (Carbajal et al., 2011; Páez, 2001; Chien, 1992). In order to determine the set of parameters, useful to assess water quality, in our work we reviewed what parameters have been used in the literature for different aquaculture systems in Mexico and Central America (Ferreira et al., 2011; Simões et al., 2008; Hirono, 1992). In Mexico, extensive and semi-extensive shrimp farms are placed in tropical or warm places. Central America countries have similar climate conditions as Mexico; therefore, shrimp practices are similar among countries, adopting those practices from extensive aquaculture systems in Mexico. Thus, we found that in most of the works (Ferreira et al., 2011; Carbajal et al., 2011; Simões et al., 2008; Páez, 2001; Chien, 1992; Hirono, 1992), dissolved oxygen, temperature and salinity are monitored daily; while, pH, ammonia, nitrates and turbidity and/or algae counts are analyzed weekly. Chemical analyses do not come into consideration for water quality management on a routine base and they are only monitored by requirement (Hirono, 1992; Carbajal et al., 2011). Non-ionized ammonia is characterized by its high toxicity for organisms and it is directly related to pH concentrations; due to this behavior and the relative simplicity for measuring pH through electronic sensors, pH is monitored daily instead of weekly. The four daily monitored variables require a special care; since a bad controlling of these parameters can disestablish the entire ecosystem, generating a potential crisis. Table 1 shows the water quality parameters organized by monitoring frequency.

In order to understand the importance and effects of these water quality parameters in a shrimp ecosystem, we provide a brief explanation of them. Tables 2–4 summarize the parameters analyzed in laboratory and their respective importance in shrimp culture. Water quality parameter descriptions are organized by monitoring frequency.

2.2. Water quality parameter levels

A good water quality condition can be determined when environmental tests of all water quality parameters fall inside their optimal range for shrimp organism. According to Tables 2–4, we can establish the optimal ranges as they have been defined in the literature. These ranges can be consulted in Table 5, grouped by monitoring frequency. In this case, the parameter deviation (d) helps to determine if a test value can be considered near or far from its desired range, this parameter is especially useful because a tight decision can directly influence the water quality assessment (see Section 3).