WATER QUALITY MANAGEMENT IN A MARINE FISH HATCHERY SYSTEM

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ABSTRACT

WATER QUALITY MANAGEMENT IN A MARINE FISH HATCHERY SYSTEM

Water quality is vitally important for any aquaculture system. The quality of water at intake point as well as changes in the quality as the water flows into the various sections of the hatchery require regular monitoring. The effect of fish in the hatchery tanks is brought to bear on water composition by release of metabolic waste and degradation of unconsumed feed among other factors. Unless remedial action is taken, water quality is impaired and this in turn produces adverse influence on growth and survival of the fish. Obviously, in order to maintain healthy operation of the aquaculture system, certain parameters have to be identified, examined and their range regulated within the tolerance limits of the fish in captivity. This thesis was designed to generate information on dynamics of water quality in a marine finfish hatchery and environment-friendly methods which can be applied to manage the water quality. The parameters monitored included temperature (^{o}C), dissolved oxygen (mg/L), pH, salinity ($^{o}/_{oo}$), total suspended solid (mg/L), turbidity (mg/L), total alkalinity (mg $CaCO_3$/L), total carbon dioxide (mg/L), NH_3+NH_4-N (mg/L), NO_2-N (µg/L), NO_3-N (mg/L), PO_4-P (mg/L), Cd (µg/L), Cr (µg/L), Cu (µg/L), Fe (µg/L) and Pb (µg/L). As a result of intensive studies the range of variations in the water quality parameters was established, the problems affecting captive fish were identified and remedial actions worked out. Water quality remediation involved application of biofilters, mainly the Aquamat^{TM} and biodynamic integration of aquaponic system with the aquaculture units. Aquamat™ is an innovative product fabricated from highly specialized synthetic polymer substrates that provided *in situ* biofiltration while the culture was under progress. The aquaponic system provided a natural filtration of water for the fish and the fish waste was made use of in growth of plant biomass. Seaweeds used as the plant component of the aquaponic system comprised of three varieties of *Eucheuma* namely, *E. spinosum* (brown and green colours) *E. cottoni*. Results showed that the seawater quality of the six sections in the hatchery was within the suitable range for marine fish culture activity. However, two sections, namely, culture tanks and the waste water required improvement for reducing NH_3-N+NH_4-N and NO_3-N concentrations. Aquamat™ reduced fish mortality, and concentrations of NH_3-N and total suspended solid. However, NO_2-N and NO_3-N concentrations remained high, which suggested that the Aquamat™ could not remove all the dissolved inorganic nitrogen from the culture system. Aquamat™ provided surface area for larval fish to hide from cannibalism, for attachment of extra feed ingredients and fish waste, and for microbes to grow, which then enhanced nitrification process. In aquaponic experiment, specific growth rate and biomass yield of *E. spinosum* were in the range of 0.36 ± 0.11 % perday to 0.42 ± 0.13 % perday and 0.95 ± 0.27 g/day/m^2 to 1.13 ± 0.32 g/day/m^2, respectively. *E. spinosum* had the capability of reducing NH_3+NH_4^+, NO_2^- and NO_3^- concentrations in culture systems. Combination biofilters of seaweed and coral rubble had higher NH_3+NH_4^+ removal percentage. Based on these findings, a combination of Aquamat™, aquaponic and coral rubble was tested as a model of bio-integrated, environmental-friendly and efficient aquatic food production system. In conclusion, this thesis yielded practically feasible water quality remediation systems that can contribute towards a low carbon sustainable aquaculture technology.

Keywords: Water quality, Marine fish hatchery, Aquaponic, Aquamat and Biofilter.

ABSTRAK

Kualiti air amat penting di dalam sistem akuakultur. Ianya memerlukan pemantauan berkala meliputi sumber air yang diperolehi dan semasa dialirkan ke bahagian-bahagian di dalam sistem hatceri. Ikan yang diternak di dalam tangki-tangki ternakan boleh menyebabkan komposisi air berubah iaitu hasil daripada metabolik buangan ternakan dan penguraian lebihan makanan yang diberikan. Sekiranya langkah perawatan tidak diambil, kualiti air menjadi rendah seterusnya menghasilkan pelbagai gejala terhadap pertumbuhan dan kemandiran ikan ternakan. Oleh itu, operasi akuakultur yang baik seharusnya mengukur dan mengenalpasti sebahagian parameter kualiti air supaya berada di dalam had julat toleransi yang sesuai untuk ternakan ikan. Tesis ini dihasilkan untuk memberikan maklumat mengenai perubahan kualiti air laut di dalam sistem hatceri ikan dan kaedah-kaedah perawatan mesra alam yang sesuai diaplikasi untuk kegunaan pengurusan. Parameter air laut yang diukur termasuklah suhu (^{o}C), oksigen terlarut (mg/L), pH, saliniti ($^{o}/_{oo}$), jumlah pepejal terampai (mg/L), turbiditi (mg/L), jumlah alkaliniti (mg $CaCO_3$/L), jumlah karbon dioksida (mg/L), NH_3+NH_4-N (mg/L), NO_2-N (µg/L), NO_3-N (mg/L), PO_4-P (mg/L), Cd (µg/L), Cr (µg/L), Cu (µg/L), Fe (µg/L) dan Pb (µg/L). Hasil daripada kajian intensif, maklumat mengenai julat kualiti air laut yang sesuai untuk kegunaan ternakan telah diwujudkan, permasalahan terhadap ternakan ikan dikenalpasti dan langkah-langkah perawatan yang dilakukan. Kaedah perawatan yang diberikan adalah penapisan bio iaitu menggunakan aplikasi Aquamat™ dan intergrasi sistem akuaponik di dalam akuakultur. Aquamat™ adalah hasilan fabrik diperbuat daripada bahan sintetik polimer yang berupaya menapis secara *in situ* di dalam sistem kulturan. Manakala akuaponik adalah sistem penapis bio semulajadi di mana bahan buangan ikan ternakan digunakan sebagai baja untuk pertumbuhan. Tiga varieti rumpai laut telah digunakan sebagai komponen akuaponik di dalam kajian ini iaitu *Eucheuma spinosum* (berwarna coklat dan hijau) dan *E. cottoni*. Hasil kajian mendapati kualiti air laut di enam seksyen hatceri berada di dalam julat yang sesuai digunakan untuk ternakan ikan, tetapi dua seksyen hatceri didapati memerlukan perhatian sewajarnya iaitu tangki ternakan ikan dan air buangan daripada ternakan kerana mengandungi NH_3-N+NH_4-N and NO_3-N yang tinggi. Selain itu, kajian juga menunjukkan Aquamat™ berupaya mengurangkan kematian ikan-ikan ternakan dan mengurangkan kepekatan NH_3-N serta jumlah pepejal terampai, tetapi kepekatan NO_2-N dan NO_3-N didapati meningkat. Aquamat™ didapati tidak berupaya mengurangkan kepekatan unsur inorganik nitrogen secara keseluruhan dari sistem ternakan. Aquamat™ menyediakan luas permukaan untuk ikan ternakan bersembunyi agar terelak daripada kanibalisma dan berupaya melekatkan lebihan makanan serta bahan buangan ternakan selain menyediakan tempat untuk mikrob berkembang dan seterusnya mempercepatkan proses nitrifikasi. Eksperimen akuaponik menunjukkan kadar pertumbuhan spesifik dan hasil biojisim *E. spinosum* masing-masing adalah dalam julat 0.36 ± 0.11 % per hari hingga 0.42 ± 0.13 % per hari dan 0.95 ± 0.27 g/hari/m^2 hingga 1.13 ± 0.32 g/hari/m^2. *E. spinosum* didapati berupaya mengurangkan kepekatan NH_3+NH_4^+, NO_2^- dan NO_3^- di dalam sistem kulturan. Kombinasi penapis rumpai laut dan batu karang diapati berkeupayaan menghilangkan peratusan kepekatan NH_3+NH_4^+ yang tinggi. Berdasarkan hasil kajian, kombinasi penapis bio yang terdiri daripada Aquamat™, aquaponik dan batu karang telah diuji untuk dijadikan model bio-integrasi, mesra alam dan sistem pengeluar makanan akuatik yang effisien. Sebagai kesimpulan, tesis ini memberikan maklumat mengenai sistem perawatan kualiti air laut yang praktikal dan berupaya mengurangkan pelepasan karbon untuk teknologi akuakultur yang mapan.

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LIST OF ACRONYMS AND ABBREVIATIONS

AAS	Atomic Absorption Spectrometry
ANOVA	Analysis of Variance
BMRI	Borneo Marine Research Institute, Universiti Malaysia Sabah
Cd	Cadmium
Cr	Chromium
CFU	Colony Forming Unit
CR	Coral rubble
Cu	Copper
DO	Dissolved oxygen
et al	et alia (and others)
Fe	Iron
g	Gram
$g/m^2/day$	Gram per metre square per day
HRMN	Hydrographic Royal Malaysian Navy
Kg	Kilogram
L	Litre
L/sec	Litre per second
m^2	Metre square
mg	Milligram
mV	Milivolt
mL	Milliliter
ORP	Oxidation Reduction Potential
Pb	Lead
RAS	Recirculating Aquaculture System
RM	Ringgit Malaysia
TA	Total Alkalinitiy
TAN	Total Ammonia Nitrogen
TCO_2	Total Carbon Dioxide
TSS	Total Suspended Solids
S	Sand
Swd	Seaweed
WQSA	Water Quality Standards For Aquaculture Activity

µg	Microgram
µmol/m^2/sec	Micromol per metre square per second
uS/cm	Microsiemens per centimeter
µg/L	Microgram per litre
%	Percentage

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CHAPTER 1

GENERAL INTRODUCTION

1.1 Introduction

High quality water in sufficient volume is a primary consideration and a major factor in fish hatchery operations and management. It is generally agreed that high quality water is the most important input for aquaculture and thus a key element in the success of all phases of culture operations (ANZECC, 2000). Slow growth and disease problems are generally linked to poor water quality. Deterioration in the quality of water increases stress on the captive animals, reduces their growth, makes them vulnerable to disease and can cause heavy mortality (Estim, 2008e; Estim, 2008f). Besides, water quality associated with aquaculture development is a matter of widespread concern since it can produce a variety of negative environmental impacts on the receiving environment (Piedrahita, 2003; Camargo and Alonso, 2006).

Gaining insight into water quality helps aquaculture become more efficient and productive. Most importantly, it is the water quality that will influence optimal growth and yield. Managing water quality is important but often, fish farmers do not have extensive training in water chemistry and as a result they may misinterpret or misapply information about water quality and its management. Water quality is defined as any characteristic of water in production systems that effect survival, reproduction, growth and production of aquaculture species. It also influences management decisions, causes environmental impacts, or reduces product quality and safety (Boyd and Tucker, 1998). Many studies have reported the effects of water quality on the aquaculture organisms and environment (Gradall and Swenson, 1982; Lawson, 1995; Taranzona and Munoz, 1995; Beveridge and Haylor, 1998; Boyd and Tucker, 1998; Colt and Tomasso, 2001). Besides, several Water Quality Standards for Aquaculture Activity (WQSA) have been published to be used as a guideline (UNDP/FAO, 1989; Rosly, 1990; Zweig *et al.,* 1999; AMWQC, 1999; ANZECC, 2000).

In year 2002 to 2004, annually marine fish production in Malaysia is about 1.4 million metric tons, with estimated value more than RM 5 billion (Mohd Fariduddin, 2008). Overall, brackish water aquaculture contributed on average 70 to 75 percent of the total aquaculture production. Pond based production which is typically for shrimp aquaculture and cage system contributed at about 5 % and 15 %, respectively in term of fish volume in marine aquaculture sector. The government put up strategies to develop marine aquaculture and clearly defined in the National Agricultural Policy (NAP3). The NAP3 was formulated and endorsed to cover periods from year 1998 to 2010. The potential and importance of fisheries was highlighted in the NAP3 and was given a significant task. Specific objectives include are to enhance food security, to increase productivity and competitiveness of the sector, to deepen linkages with other sectors, to create new sources of growth for the sector, and to conserve and utilize natural resources on a sustainable basis.

Besides, a guideline on Good Aquaculture Practices (GAqP) to mitigate environmental impact has been implemented by Department of Fisheries Malaysia, which is mainly for shrimp industry (FAO, 2004). The guidelines uphold the standard requires by international body such as Fisheries and Agriculture Organization (FAO). The same guideline soon will be developed for marine finfish aquaculture activities and others (Mohd Fariduddin, 2008). A major task by government currently is however is to ensure that the guideline is practice by culturist, of particular the downstream farmers.

A practical water quality understanding in aquaculture is essential because it allows an assessment of environmental conditions and implementation of effective management strategies. No doubt, in order to keep the health of any aquaculture system at an optimal level, certain water quality parameters must be monitored and controlled. Water quality parameters outside the acceptable range will stress the fish in aquaculture systems. Therefore, it is equally important to know how to interpret the water quality parameters that are measured to maintain the health and well-being of the fish in aquaculture systems. While chemistry of water is a complex subject, most aspects of general importance to farmers can be simplified to allow for easier understanding and practical approaches to management.

This thesis describes water quality management in a marine fish hatchery system at the Borneo Marine Research Institute (BMRI) of Universiti Malaysia Sabah, Malaysia. The BMRI Fish Hatchery receives seawater from the Sepanggar Bay area (Figure 1.1 and Figure 1.2). Daily total seawater capacity for the hatchery is approximately 1320 metric tone. Larval high mortality and failure of spawning are some of problems that need to be addressed (Personnel communication with BMRI staff). These could be due to water quality or some other factors.

The thesis presents a detailed account of the seawater quality profile in different sections of the hatchery with the aim of establishing the range of variations in the water quality parameter and identifying problems, if any, that affect the captive fish. The seawater temperature, dissolved oxygen (DO), pH, salinity, total suspended solid (TSS), turbidity, total alkalinity (TA), total carbon dioxide (TCO_2), dissolved inorganic nutrients (NH_3-N, NO_2-N, NO_3-N and PO_4-P) and heavy metals (Cd, Cr, Cu, Fe and Pb) were determined (Estim *et al.,* 2008a; Estim, *et al.,* 2008b; Estim *et al.,* 2009a; Estim *et al.,* 2009c). The study concluded that while the water quality in the hatchery is within the suitable range for marine fish culture activity, there are some sections that require attention for improvement, particularly the culture tanks and the waste water which recorded higher levels of NH_3-N and NO_3-N.

High ammonia concentration can cause gill damage, reduce the oxygen carrying capacity of blood, increase the oxygen demand of tissues, damage red blood cells and affect osmoregulation (UNDP/FAO, 1989; Zweig *et al.,* 1999 and ANZECC, 2000). Although NO_3 is relatively non-toxic to aquatic organisms, but it should not be left to accumulate because it eventually leads to some undesirable conditions such as phytoplankton blooms. NO_3-N has been known for stimulating harmful algal bloom in the marine waters of Sabah, even in a low concentration (Estim, 1999; Estim *et al.,* 2001). Van Rijn (1996) explained the most common water quality problem in intensive fish culture systems is inorganic nitrogen,

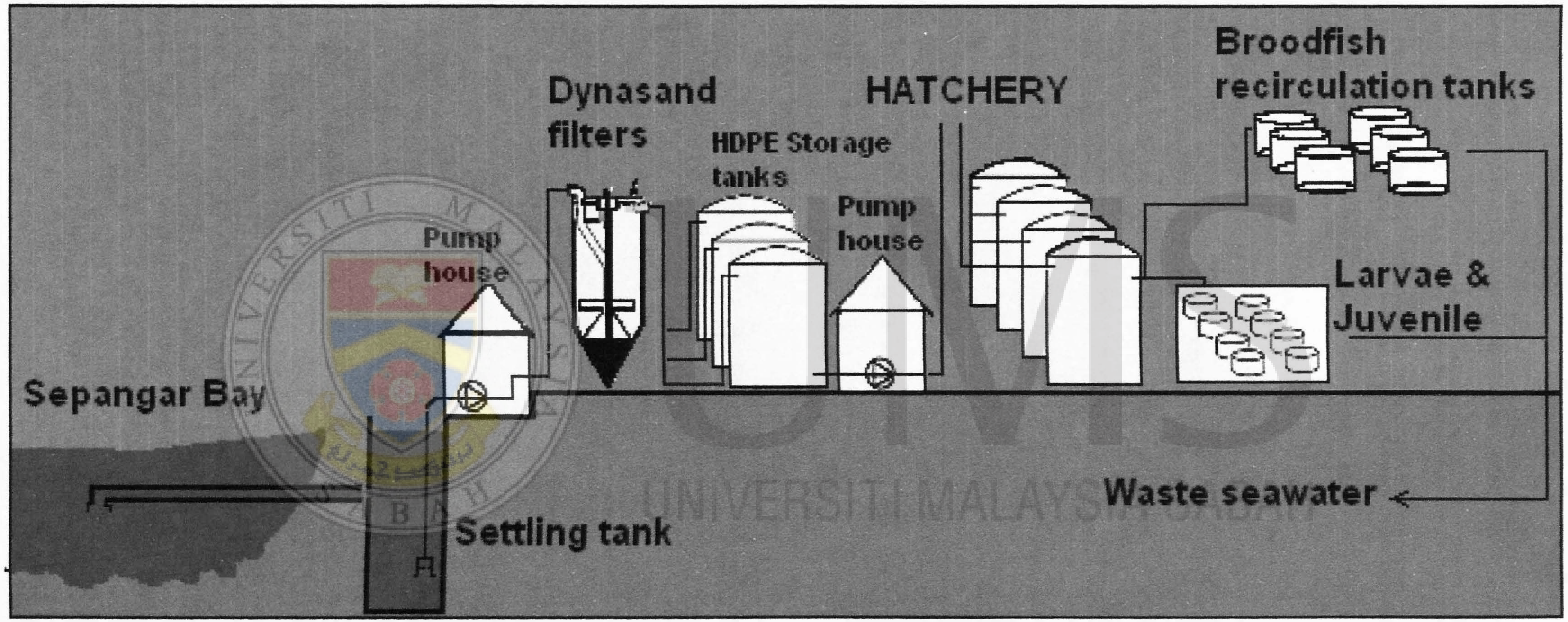

Figure 1.1 **Layout of the Fish Hatchery, Borneo Marine Research Institute of Universiti Malaysia Sabah**

particularly ammonia. Some of the negative impacts on aquaculture practices are due to release of nitrogen and phosphorus that can cause eutrophication and deteriorate the environment (Camargo and Alonso, 2006). The feeds supplied to the captive stocks are discharged into the environment and often constitute around 75 % of the waste in water, which may cause environmental and socio-economic problems, and also affect the aquaculture activity itself (Piedrahita, 2003).

Biofilter systems namely, Aquamat™, and the Aquaponic system responsible to reduce NH_3-N concentration in the culture systems and the waste water are explained in chapters 4 and 5. Information on biofilters in marine fish hatchery is very limited. This thesis provides information on Aquamat™ and Aquaponic biofilter applications to supplement the meagre amount of data on this aspect. These biofilters are responsible for reducing dissolved inorganic nitrogen concentrations in marine fish hatchery (Estim and Mustafa 2006; Estim *et al.,* 2008c; Estim *et al.,* 2008d; Estim *et al.,* 2009b; Estim *et al.,* 2009c; Estim *et al.,* 2009d; Estim *et al.,* 2009e; Estim and Mustafa, 2010).

Aquamat™ is a new and innovative product fabricated from highly specialized synthetic polymer substrates (Figure 1.3). It forms a complex three-dimensional structure and resembles seagrass in appearance. This product has been principally used to support high stocking densities in fish culture ponds (Scott and McNeil, 2001) and enhancing biological processes in ornamental fish ponds (Ennis and Bilawa, 2000). Bratvold and Browdy (2001) observed decrease in NH_3-N concentration using the Aquamat™ and sand sediment to treat shrimp farm waste water. These findings support further research involving Aquamat™ potential benefits for improving seawater quality in marine fish hatchery are explained in the chapter 4. The findings contained in this chapter have seen positive results (Estim *et al.,* 2008d; Estim *et al.,* 2009c).

Different species of seaweeds have been studied for their suitability as a nutrient biofilter (Ryther *et al.,* 1975; Harlin *et al.,* 1978). These include *Asparagopsis armata, Ecklonia, Gracilaria crassa, Gracilaria gracilis, Gracilaria lemaneiformis, Kappaphycus alverazii, Ulva lactuca, Ulva reticulata, Ulva*