Annex 2.

Water Quality Criteria and Standards for Freshwater and Marine Aquaculture

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Mitigating Impact from Aquaculture in the Philippines

Abbreviations and Acronyms

ANZECC	Australia and New Zealand Environment and Conservation Council
AMEQC -	ASEAN Marine Environmental Quality Criteria
ASEAN-	Association of Southeast Asian Nation
CCME-	Canadian Council of Ministers of the Environment
DENR -	Department of Environment and Natural Resources
EPA -	Environmental Protection Agency
EPD -	Environmental Protection Department
EMB -	Environment Management Bureau
EMCR -	Environmental Management and Coordination (Water Quality) Regulations
EPA -	Environment Protection Authority
NEMA-	National Environment Management Authority
OATA -	Ornamental Aquatic Trade Association
PWD -	Public Works Department
SFT -	Statens forurensningstilsyn (Norwegian Pollution Control Authority)
USEPA-	United States Environment Protection Authority

INTRODUCTION

In 2004, capture fisheries and aquaculture have supplied the world with 106 million tons of food fish (FAO, 2006). Of this, 43% came from aquaculture. In the Philippines, aquaculture has contributed significantly, i.e. 2,093,371 mT in 2006 when compared with the total fishery production of 2,316,185.77 mT (BAS, 2006).

Within the growing aquaculture industry, it is accepted that good water quality is needed for maintaining viable aquaculture production. Poor water quality can result in low profit, low product quality and potential human health risks. Production is reduced when the water contain contaminants that can impair development, growth, reproduction, or even cause mortality to the cultured species. Some contaminants can accumulate to the point where it threatens human health even in low quantities and cause no obvious adverse effects.

The fish perform all its physiological activities in the water – breathing, excretion of waste, feeding, maintaining salt balance and reproduction. Thus, water quality is the determining factor on the success or failure of an aquaculture operation. The continued degradation of water resources due to anthropogenic sources necessitates a guideline in selecting sites for aquaculture using water quality as a basis.

This paper reviews the water quality standards set by different countries. Each parameter is provided with basic information and a scientific basis for each value set as standard. It aims to provide useful information on water quality standards that the Philippine government and aquaculture operators can adapt, with a primary objective of promoting higher production yield, better product quality, and with a minimum impact to the environment.

The information contain here is limited to available literatures and country standards. Moreover, the standards set by the ASEAN are still at interim stage. Cultured species as well as production system may not all be covered.

Physical Parameters

pH

The term pH was originally derived from a French word, "*pouvoir hydrogéne*", which means "hydrogen power". This parameter shows the quantity of hydrogen ions (H^+) in the water.
The scale for measuring the degree of acidity is called the pH scale, which ranges from 1 to 14. At 25 ^{0}C, pH of 7.0 will be considered neutral, i.e. neither acidic nor basic, while values below 7.0 are considered acidic, and above 7.0 are basic. Natural waters range between pH 5.0 and pH 10.0 while seawater is near pH 8.3. A pH meter is an electronic instrument used to measure the pH of a liquid, and typically it consists of a special measuring probe (a glass electrode) connected to an electronic meter that measures and displays the pH reading.

The pH is interdependent with other water quality parameters, such as carbon dioxide, alkalinity, and hardness. It can be toxic in itself at a certain level, and also known to influence the toxicity as well of hydrogen sulfide, cyanides, heavy metals, and ammonia (Klontz, 1993).

The pH can also affect fish health. For most freshwater species, a pH range between 6.5 - 9.0 is ideal, but most marine animals typically cannot tolerate as wide range pH as freshwater animals, thus the optimum pH is usually between pH 7.5 and 8.5 (Boyd, 1998). Below pH 6.5, some species experience slow growth (Lloyd, 1992). At lower pH, the organism's ability to maintain its salt balance is affected (Lloyd, 1992) and reproduction ceases. At approximately pH 4.0 or below and pH 11 or above, most species die (Lawson, 1995). Table 1 shows the effects of different pH levels to warm water pond fish, while Table 2 shows the recommended value for salmonid aquaculture production.

Table 1. pH tolerance levels and its effect on aquaculture

pH levels	Effects on warm water pond fish
< 4.0	Acid death point
4.0 – 5.0	No production
6.5 - 9.0	Desirable range for fish production
9.0 - 11.0	Slow growth
> 11.0	Alkaline death point

Source: Lawson 1995, Tarazona and Munoz 1995

The pH of pond water increases daily as phytoplankton consume carbon dioxide during photosynthesis (reaching a maximum value near 6 PM), and decreases at night as they release carbon dioxide during respiration (reaching a minimum value near 6 AM). Indirectly, changes in pH can also affect aquatic organisms. In fish ponds, the low pH levels can accelerate the release of metals from rocks and sediments. These metals can affect the metabolism of the fish and its ability to take up water through the gills. Moreover, low pH can reduce the amount of dissolved inorganic phosphorous and carbon dioxide available for phytoplankton during photosynthesis. Ponds with low pH values (< 5) receiving acid rain, mine acid drainage or acidic swamp water can be improved by liming. On the other hand, high pH levels, can make the toxic form of ammonia become more prevalent, and the phosphate, which is commonly added as a fertilizer, can rapidly precipitate (Boyd, 1990).

Table 2. Ideal pH levels for salmonid culture

Recommended range of pH levels for fish production
6.4–8.4
6.7–8.6
6.7–7.5

Source: Lawson 1995, Tarazona and Munoz 1995

Table 3 shows the different range of pH some countries are implementing. Generally, all countries use an average range of between 5.0 and 9.0 in freshwater, and 6.5 and 9.0 for marine, all of which are within the limits of optimum fish production.

Table 3. Acceptable pH levels for fish production

Country	Freshwater	Marine water	Reference
Australia	5.0 - 9.0	6.0 - 9.0	ANZECC, 2000

Brunei Darussalam	6.9		PWD
Canada	6.5-9.0		CCME, 1994
Hong Kong		6.5-8.5	EPD, 1999
India		6.5 – 8.5	
Kenya	5.0 – 9.0		EMCR, 2006
Malaysia	6.5 - 9.0	6.5 - 9.0	
New Zealand	5.0 – 9.0	6.0 – 9.0	ANZECC, 2000
Philippines	6.5 - 8.5	6.5 - 8.5	DAO 1990-34

Total Alkalinity

In aquaculture, alkalinity is the measure of the capacity of water to neutralize or buffer acids using carbonate, bicarbonate ions, and in rare cases, by hydroxide, thus protecting the organisms from major fluctuations in pH. Without a buffering system, free carbon dioxide will form large amounts of a weak acid (carbonic acid) that may potentially decrease the night-time pH level to 4.5. During peak periods of photosynthesis, most of the free carbon dioxide will be consumed by the phytoplankton and, as a result, drive the pH levels above 10.0. As discussed, fish grow within a narrow range of pH values and either of the above extremes will be lethal to them. Table 3 and 4 show the recommended alkaline values for aquaculture production and natural system, respectively.

Moreover, carbonates and bicarbonates can act as a storage area for surplus carbon dioxide, thus carbon dioxide will not be limited during photosynthesis. This will then ensure that there will be a continuous supply of oxygen in the system.

Table 4. Recommended alkaline levels for aquaculture production

Total alkaline value (mg/L)	**Species**
≥ 20	Catfish
≥ 80-100	Hybrid striped bass

Table 5. Recommended alkaline levels in natural system

Total alkaline value (mg/L)	**Natural System**
5-500	Freshwater
116 (mean value)	Seawater

Source: Lawson, 1995

Table 6 shows the standards for alkalinity in freshwater environment set by Australia and New Zealand. It is good to note that the Philippines has not yet set any standard value for this parameter. As mentioned above, alkalinity is a good indicator of pH level in the system. On the other hand, the values set in Australia and New Zealand are comparative with those recommended by Lawson (1995).

Table 6. Acceptable levels of alkalinity at freshwater environment

Country	Alkalinity (mg/L)	Source
Australia	≥ 20	ANZECC, 2000
New Zealand	≥ 20	ANZECC, 2000
Philippines	*	

*No standard set

Dissolved Oxygen (DO)

In a water body, oxygen is available in a dissolved state. It is found in microscopic bubbles mixed in between water molecules. It can enter into the system through direct diffusion and as a by-product of photosynthesis. This means then that the level of dissolved oxygen in the water can be increased through mechanical aeration, e.g. paddle wheels, agitators, vertical sprayers, impellers, airlift pumps, air diffusers, liquid oxygen injection, etc., considerable wind and wave action, and presence of aquatic plants and algae. However, caution should be considered on the latter since it can also cause oxygen depletion when the plant population becomes too dense. On the other hand, it is removed through respiration and decomposition.
Oxygen concentration maybe reported in terms milligram per liter (mg/L) or its equivalent, parts per million (ppm).
The oxygen concentration is measured in terms of parts per million (ppm) or mg/L, both units of measure are the same.

Dissolved oxygen is considered as one of the most important aspect of aquaculture. It is needed by fish to respire and perform metabolic activities. Thus low levels of dissolved oxygen are often linked to fish kill incidents. On the other hand, optimum levels can result to good growth, thus result to high production yield. In general, a saturation level of at least 5 mg/L is required (Table 7). Values lower than this can put undue stress on the fish, and levels reaching less than 2 mg/L may result to death (but 3 mg/L to some species).

Table 7. Recommended levels of dissolved oxygen for some aquaculture species

Species	DO (mg l^{-1})	Comment	Reference
Tilapia	> 5.0	Preferred	Lloyd 1992
	3.0–4.0	Tolerable	
Trout	10.0	Normal at 15°C	Lloyd 1992
	5.0	Limit for acclimation	
Marine fish	> 6.0	Minimum	Huguenin and Colt 1989
Cold water fish	> 6.0	Minimum	Lawson 1995
Salmonids	> 5.0	Can only survive lower DO for a few hours	Lloyd 1992
	> 5.5 fish		Roberts and Shepherd 1974
	> 7 eggs		
Salmon	> 8.5	Optimal	Black 1991
	100% saturation		
Warm water crustaceans	> 5	Can only survive lower DO for a few hours	Lloyd 1992
Eel	> 5	Preferred	Lloyd 1992
	3.0–4.0	Tolerable	
Carp	> 5.0	Preferred	Lloyd 1992
	3.0–4.0	Tolerable	
Fish in muddy ponds or warm, slow rivers	Resistant to low DO	Example: goldfish	Lloyd 1992
Warm water fish		More tolerant to low DO than cold water species	Lloyd 1992
	> 5.0	Recommended	Lawson 1995
	> 1.5	Live for several days	
	> 1.0	Live for several hours	
	< 0.3	Lethal concentration	
Channel catfish	< 0.5 (fingerlings)	Survive short exposure	Lawson 1995
	0.5 (adults)	Survive short exposure	Lawson 1995
	2.0–3.0	Adults survive, eggs die	Lawson 1995
	< 5.0	Feed poorly, grow slowly	Lawson 1995
	< 6.0 (hatchery)		Boyd 1990
Red swamp crawfish	< 1.0 (juveniles)	Survive short exposure	Avault *et al.* 1974
	< 2.0	Adults crawl out	Lawson 1995
Penaeid shrimp species	low DO	Like freshwater fish	Boyd 1990
	0.7–1.4	Lethal concentration	Lawson 1995
P. vannamei	6.0–10.0	Optimum	Clifford 1994
General guideline	> 5.0–6.0		Lawson 1995

Source: Zweig, Morton and Stewart, NACA

The amount of oxygen consumption varies, depending on the size, feeding rate, activity level and species. Physical condition such as temperature, altitude and salinity can also affect oxygen level. Table 8 shows the correlation between temperature, salinity and oxygen solubility. This table shows that as the temperature and salinity increases, the solubility of oxygen in the water decreases. It is for this reason that aeration can be used as an option during summer months especially in areas where the aquaculture activity is intense to avoid fish kills.

Table 8. Relationship between salinity, temperature and oxygen solubility (mg/L)

Salinity	Temperature (°F)				
	68	71.6	78.8	82.4	86
0	9.2	8.8	8.2	7.9	7.6
5,000	8.7	8.4	7.8	7.5	7.3
10,000	8.3	8.0	7.4	7.1	6.9

Other organisms such as bacteria, phytoplankton, and zooplankton also need oxygen, thus compete for dissolved oxygen with fishes. Decomposition of organic materials is the greatest consumer of oxygen in the system. Therefore food wastage and feed quality should be monitored as both significantly affect the levels of dissolved oxygen in the system

Oxygen is also needed by other organisms such as bacteria, phytoplankton, and zooplankton. They consume large amounts of dissolved oxygen as well. Decomposition of organic materials is the greatest consumer of oxygen in the system. Therefore food wastage and feed quality should be monitored as both significantly affect the levels of dissolved oxygen in the system.

Setting the guidelines for dissolved oxygen for aquaculture can be difficult, because as mentioned above, this is affected by many factors. However, most of the countries listed below (Table 9) had set ≥5.0 mg/L as the ideal concentration both for marine and freshwater. The Philippines, together with Australia, India, New Zealand, United Kingdom and ASEAN are among these countries. This value is within the values recommended by Lawson (1995) and different scientists (Table 7) which is ideal for aquaculture operations. Malaysia, on the other hand, has set the lowest value at 3.0 mg/L, followed by Hongkong at ≥4.0 mg/L.

Table 9. Acceptable levels of dissolved oxygen in freshwater and marine.

Country	Freshwater (mg/L)	Marine (mg/L)	Reference
Australia	> 5.0	> 5.0	ANZECC, 2000
ASEAN		4.0	AMEQC, 1999
Canada	6- warmwater 9.5 – cold water		CCME, 1994
Hongkong	N.D.	≥ 4.0	EPD
India	N.D.	5.0	
, Malaysia	3.0 – 7.0	3.0 – 7.0	
New Zealand	> 5.0	> 5.0	ANZECC, 2000
Philippines	5.0	5.0	DAO 1990-34
South Australia	> 6.0	> 6.0	EPA
United Kingdom	≥ 5.5		OATA

N.D. (no data available)

Biological Parameters

Nitrogen

Nitrogen is one of the limiting nutrients during photosynthesis. It enters into the aquaculture system through rainfall, in-situ N_2 fixation, river run-off, and diffusion from sediments, uneaten feeds, and fish wastes. Nitrogen is largely controlled by redox reactions mediated by phytoplankton and bacteria. The processes include remineralization, ammonification, nitrification, denitrification and fixation.

Ammonia-Nitrogen (NH_3-N)

Ammonia is the initial product of the decomposition of nitrogenous organic wastes and respiration. Nitrogenous organic wastes come from uneaten feeds and excretion of fishes. Thus, the concentration of ammonia-N is positively correlated to the amount of food wastage and the stocking density. Total Ammonia Nitrogen (TAN) is a parameter that measures the un-ionized (NH_3) and ionized (NH_4^+) forms of ammonia present in the aquaculture system.

High concentrations of ammonia causes an increase in pH and ammonia concentration in the blood of the fish which can damage the gills, the red blood cells, affect osmoregulation, reduce the oxygen-carrying capacity of blood and increase the oxygen demand of tissues (Lawson, 1995). Generally, NH_4^+ is harmless and can dissipate into the atmosphere easily, however, NH_3 can be extremely toxic. Its toxicity was found out to be directly correlated with temperature and pH, i.e. NH_3 levels increases as the temperature and pH increases (please see Table 10. NH_3 values are expressed in blue colored text).

Table 10. Percentage of NH_3-TAN at various temperatures and pH

Temperature (°F)	pH								
	7.0	7.4	7.8	8.2	8.6	9.0	9.2	9.6	10.0
54	0.2	0.5	1.4	3.3	7.9	17.8	35.2	57.7	68.4
62	0.3	0.7	1.8	4.5	10.6	22.9	42.7	65.2	74.8
68	0.4	1.0	2.5	5.9	13.7	28.5	50.0	71.5	79.9
75	0.5	1.3	3.2	7.7	17.3	34.4	56.9	76.8	84.0
82	0.7	1.7	4.2	11.0	21.8	41.2	63.8	81.6	87.5
90	1.0	2.4	5.7	13.2	27.7	49.0	70.8	85.9	90.6

To calculate the NH_3 percentage from TAN, multiply TAN concentration (in mg/L) by the percentage which is closest to the observed temperature and pH of the water sample. Generally, concentration levels below 0.02 ppm are considered safe. However, the level of NH_3 can be reduced and be converted into harmless nitrates through biological processes. Species-specific tolerance levels to NH_3 are listed in Table 11. Since there is no consensus yet on the permissible levels of ammonia, it is best to be conservative.

Table 11. Ammonia tolerance levels of some aquaculture species

Species	Ammonia (mg l^{-1} of NH_3)	Comment	Reference
M. rosenbergii	0.09	Reduced growth rates	Boyd 1990
Penaeid shrimp	0.45	50% growth reduction	Boyd 1990
P. monodon	< 0.13	Safe concentration	Boyd 1990
P. vannamei	< 0.1	Optimum	Clifford 1994
	0.1–1.0 mg l^{-1} TAN	Optimum	
Freshwater fish	< 0.05	Safe concentration	Lawson 1995
	< 1.0 mg l^{-1} TAN		
Channel cat. hatchery	< 0.05	Optimum	Boyd 1990
Salmonid hatchery	< 0.0125	Upper limit	Piper *et al.* 1982
Salmonids	< 0.02		EU 1979
Marine fish	< 0.01	Safe concentration	Huguenin and Colt 1989
General guidelines	< 1.0 mg l^{-1} TAN	Permissible level	Meade 1989
	0.1	Max tolerable level	Pillay 1992
	< 0.012	Permissible level	Boyd 1990
	< 0.02	Permissible level	Meade 1989

Complied by: Zweig, Morton and Stewart, NACA)

Nitrite-Nitrogen (NO_2-N)

Nitrite is a by product of oxidized NH_3 or NH_4^+, an intermediary in the conversion of NH_3 or NH_4^+ into NO_3. This process is completed through nitrification which is done by the highly aerobic, gram-negative, chemoautotropic bacteria found naturally in the system. The conversion is quick, thus high nitrite concentrations are not commonly found. However, if high levels do occur, it can cause hypoxia, due to deactivation of hemoglobin in fish´ blood, a condition known as the "brown blood disease" (Lawson, 1995).

The toxicity of nitrite is dependent on chemical factors such as the reduction of calcium-, chloride-, bromide- and bicarbonate ions, and levels of pH, dissolved oxygen and ammonia. One example is the culture of milkfish in freshwater, wherein nitrite is 55 times more toxic than in brackish and marine water (Boyd, 1990). Thus it is advisable to impose more stringent nitrite standards in freshwater aquaculture operations. Optimum nitrite levels for some aquaculture conditions are shown in Table 12.

In terms of other factors, such as the effect of pH, DO and ammonia on nitrite, it is found out that increasing pH, low dissolved oxygen and high ammonia can increase its toxic effect. Other evidence also shows that high nitrite concentrations plus low chloride levels can result to reduced feeding activities, poor feed conversions, lower resistance to diseases and susceptibility to mortality (Lawson, 1995). To counteract nitrite toxicity of fish is to treat water with sodium chloride or calcium chloride to reduce molar ratio of nitrite to chloride, for channel catfish Tucker et al. (1989) suggested a 20chloride1:NO_2-N ratio (Boyd, 1998) The suggested treatment is to add 3 mg/L of chloride (usually in the form of NaCl = 62% Cl) for every 1 mg/L of nitrite.

Nitrate-Nitrogen (NO_3-N)

Nitrate is formed through nitrification process, i.e. oxidation of NO_2 into NO_3 by the action of aerobic bacteria. Nitrate not taken up directly by aquatic plants is denitrified in anaerobic sediments and microzones. In tropical systems, denitrification will be most intense in the following areas: (a) where detritus accumulates; (b) in water bodies subject to enhanced nutrient loading from pollution; (c) in water bodies with long residence times; and (d) in wetland ecosystems subject to periodic drying, where oxygen inputs during drying periods stimulate coupled mineralization-nitrification-denitrification within organically rich sediments (Furnas, 1992).

Generally, it is stable over a wide range of environmental conditions and is highly soluble in water. Compared with other inorganic nitrogen compounds, it is also the least toxic. However, high levels can affect osmoregulation, oxygen transport, eutrophication and algal bloom (Lawson, 1995). Some species-specific optimum nitrate levels are found in Table 13.

Table 12. Optimal nitrite levels for some aquaculture species

Species or water	*Concentration (mg l^{-1})*	*Comment*	*Reference*
Hard freshwater	< 0.1		Pillay 1992
Soft water	< 0.1		Meade 1989
Freshwater fish	< 0.5	Hatcheries	Swann 1993
Brackish water shrimp	< 4.5		Boyd 1990
P. monodon	< 4.5	Postlarval growout	Boyd 1990
P. vannamei	< 1.0	Optimum	Clifford 1994
Salmonid	< 0.01	Soft water	Pillay 1990
	< 0.1	Hard water	

Table 13. Optimal nitrate levels for some aquaculture species

Species	*Concentration (mg l^{-1})*	*Comment*	*Reference*
Carp	< 80	Optimum	Svobodová *et al.* 1993
Trout	< 20	Optimum	Svobodová *et al.* 1993
P. vannamei	0.4–0.8	Optimum	Clifford 1994
Freshwater hatchery	< 3	Optimum	Piper *et al.* 1982
General guidelines	< 3 < 100	Permissible	Meade 1989 Pillay 1992

Moreover, nitrate was considered to be less toxic than nitrite to both the tiger prawn, *P. monodon,* and the Malaysian giant prawn, *M. rosenbergii* (Wickins, 1976). Growth of *P. monodon* was not affected in 3-5 week exposures to concentrations above 200 mg/L NO_3-N; the LC50 and EC50 values for survival and growth of *M. rosenbergii* were 160 mg/L NO_3-N and 175 mg/L NO_3-N, respectively, for a 3-week exposure.

A nitrate concentration of 450 mg/L nitrate-N caused extended larval development in the shrimp, *Paleomonetes pugio* (Hinsman, 1977; cited in Colt and Armstrong, 1981).

Table 14 shows the standards set by different countries for NH_4^+, NH_3, NO_3, NO_2 both for freshwater and marine. Among the countries compared, Australia and New Zealand have specific standards for all forms of inorganic nitrogen.

Table 14. Acceptable levels of nitrogen in freshwater and marine

Country	**NH_4^+-N (mg/L)**		**NH_3-N (mg/L)**		**NO_3–N (mg/L)**		**NO_2–N (mg/L)**		**Reference**
	Freshwater	Marine	Freshwater	Marine	Freshwater	Marine	Freshwater	Marine	
ASEAN				0.07				0.055	AMEQC, 1999
Australia	< 1.0	< 1.0	< 0.03	< 0.01	50	< 100	0.10	< 0.10	ANZECC, 2000
Canada			2.2, at pH 6.5 1.37 at pH 8.0				0.06		CCME, 1994
Hongkong				≤ 0.021					EPD
Malaysia	0.3 (TAN)		0.3 (TAN)		7.0		0.40		
New									ANZECC,

Zealand	< 1.0	< 1.0	< 0.03	< 0.01	50	< 100	0.10	< 0.10	2000
Philippines					10				DAO 1990-34
South Australia	0.5	0.2	0.01	0.05					EPA

In terms of NH_4^+ standard, Australia, New Zealand and South Australia have the value set at less than 1.0 mg/L for both freshwater and marine, while Malaysia requires 0.3 mg/L of TAN for freshwater. South Australia has a more stringent criteria for NH_3, with a value of 0.01 mg/L for freshwater, compared to Australia and New Zealand, which provides a maximum allowable limit of up to 0.03 mg/L. The general standard is 0.02 mg/L.

Standards for NO_2 and NO_3 are not very critical, as these will not pose any harm to the species cultured if not present in a very high concentration. However, the values should be lower in freshwater than in marine, contrary to the values set by New Zealand and Australia, as ions are present in marine waters can reduce its toxicity.

It is worthy to note that the Philippines have only existing criteria for NO_3 level for freshwater. Criteria for NH_3 and NH_4 levels, both for freshwater and marine are lacking. It is very important that these standards be set not only to maximize the production but also to have a sustainable industry. The government's program of intensifying aquaculture can only be achieved if the quality of the environment will be able to sustain these activities.

Phosphorous (P)

Phosphorus (P) is found in the form of inorganic and organic phosphates (PO_4) in natural waters. Inorganic phosphates include orthophosphate and polyphosphate while organic forms are those organically-bound phosphates. Phosphorous is a limiting nutrient needed for the growth of all plants- aquatic plants and algae alike. However, excess concentrations especially in rivers and lakes can result to algal blooms. A lake with a concentration of below 0.010 mg/L is considered as oligotrophic, while concentrations between 0.010 and 0.020 mg/L are indicative of mesotrophy, and concentrations exceeding 0.020 mg/L are already considered eutrophic (Muller and Helsel, 1999). Phosphates are not toxic to people or animals, unless they are present in very high levels. Digestive problems could occur from extremely high levels of phosphates.

Among the common sources of phosphorous are wastewater and septic effluents, detergents, fertilizers, soil run-off (as phosphorous bound in the soil will be released), phosphate mining, industrial discharges, and synthetic materials which contain organophosphates, such as insecticides. Aquaculture farms located near these sources can expect to have higher concentrations of phosphates in the water bodies. Total phosphorus associated with suspended matter in unpolluted tropical rivers normally ranges between 620 – 1860 µg/L (Furnas, 1992). Desorption experiments demonstrated the capacity for rapid phosphorus release within estuaries (<1 day), with final particle-bound phosphorus concentrations stabilizing between 15.5 and 77.5 µg/L. These concentrations are of similar magnitude to dissolved reactive phosphorus (15.5 to 31 µg/L) in river waters (Furnas, 1992).

Phosphorous concentration is measured either by using Total phosphorus (TP), which is a measure of all the various forms of phosphorus that are found in a water sample or by Soluble

Reactive Phosphorous (SRP), which measures organophosphate, the soluble, and inorganic form of phosphorous which is directly taken up by the plants. The acceptable levels of phosphorus (in different forms) by each country are given on Table 15.

Table 15. Acceptable levels of phosphorous (in different forms)

Country	Freshwater (mg/L)	Marine (mg/L)	Reference
Australia	< 0.10 (PO_4)	< 0.05 (PO_4)	ANZECC, 2000
ASEAN		0.015 (dissolved P)	AMEQC, 1999
Malaysia	0.10 – 0.20 (P)		
New Zealand	< 0.10 (PO_4)	< 0.05 (PO_4)	ANZECC, 2000
Norway	$\leq$ 0.025 (P)	$\leq$ 0.025 (P)	SFT
Philippines	0.05 - 0.10 (P) (lakes and reservoir) 0.20 (all others) (P)	Nil (as organophosphate)	DAO 1993-34
United States	0.05 (point source) 0.10 (non-point source)		EPA

Quality standards on phosphorous levels (in different forms) set by Australia, ASEAN, Malaysia, New Zealand, Norway, Philippines and United States, are between 0.02 and 0.20 mg/L for freshwater and from nil to 0.20 mg/L for marine. This shows that the marine environment is more sensitive to phosphorous level changes, thus is required to have a value lower than freshwater. Algal blooms, red tides, and fish kills occurring show this sensitivity more frequent in marine water and less likely in freshwater environment.

In the Philippines, the standard values are the same as that of the United States. But compared with other countries mentioned, it is more stringent, requiring P levels as low as 0.05 mg/l for freshwater and nil for marine waters.

Total Solids

Total solids refer to any matter either suspended or dissolved in water. Everything that retained by a filter is considered a suspended solid, while those that passed through are classified as dissolved solids, i.e. usually 0.45µ in size (American Public Health Association, 1998). Concentrations in water are both measured as Total Suspended Solids (TSS) and Total Dissolved Solid (TDS), respectively.

Suspended solid (SS) can come from silt, decaying plant and animals, industrial wastes, sewage, etc. They have particular relevance for marine organisms that are dependent on solar radiation and those whose life forms are sensitive to deposition. High concentrations have several negative effects, such as decreasing the amount of light that can penetrate the water, thereby slowing photosynthetic processes which in turn can lower the production of dissolved oxygen; high absorption of heat from sunlight, thus increasing the temperature which can result to lower oxygen level; low visibility which will affect the fish' ability to hunt for food; clog fish' gills; prevent development of egg and larva. It can also be an indicator of higher concentration of bacteria, nutrients and pollutants in the water.

Some of the factors that affect the concentration of SS are high flow rate, soil erosion, urban run-off, septic and wastewater effluents, decaying plants and animals and bottom-feeding fish.

Dissolved solid (DS), on the other hand includes those materials dissolved in the water, such as, bicarbonate, sulphate, phosphate, nitrate, calcium, magnesium, sodium, organic ions, and other ions. These ions are important in sustaining aquatic life. However, high concentrations can result to damage in organism's cell (Mitchell and Stapp, 1992), water turbidity, reduce photosynthetic activity and increase the water temperature. Factors affecting the level of dissolved solid in water body are urban and fertilizer run-off, wastewater and septic effluent, soil erosion, decaying plants and animals, and geological features in the area.

Table 16 shows the standards set by the ASEAN, Australia, Kenya, Malaysia, New Zealand, Philippines and South Australia. Generally, these countries give more emphasis on TSS standards than with TDS. Among the countries, the average TSS value is less than 40 mg/L for freshwater and less than 10 mg/L for marine. However, Malaysia accepts a value of up to 150 mg/L for freshwater. For the TDS, only Kenya and Malaysia have a required standard, which ranges between 500 to 1,200 mg/L.

Table 16. Acceptable levels of total solids for freshwater and marine environment

Country	TSS (mg/L)		TDS (mg/L)		Reference
	Freshwater	Marine	Freshwater	Marine	
ASEAN		≤10% increase			AMWQC, 1999
Australia	< 40	< 10			ANZECC, 2000
Canada	< 10%				CCME, 1994
Hong Kong		< 30%			EPD, 1998
Kenya	30	30	1,200	1,200	NEMA
Malaysia	25 - 150		500-1000		
New Zealand	< 40	10			ANZECC, 2000
Philippines	≤ 30% (increase)	≤ 30% (increase)			DAO 1990-34
South Australia	20	10			EPA

N.A. = not available

The Philippines and ASEAN does not have a specific standard for TSS and lacks a standard for TDS. The acceptable TSS value is based on the previous sampling, wherein it should not increased by more than 10% and 30%, respectively. It is because TSS levels in marine waters are highly variable and depend on many factors, thus, setting an absolute numerical value is not possible.

However, this kind of criteria can be ambiguous. One, if the previous measurements are inaccurate, then using them as a basis will not give you the true condition of the water quality, thus, this can be dangerous. In addition to that, the totality of the contribution of all effluents, e.g. uneaten feeds, fish' fecal matters, agricultural run-off, etc. will be difficult to detect using percentage increase since their impact will not be spread out evenly in the water body. And lastly, monitoring the changes and condition of the water quality will be a challenge.

Regulating aquaculture activities, e.g. setting maximum allowable number of cages, stocking density, ideal sites, etc. need to have a sound basis in order to maximize its full potential and sustainability of the industry cannot be achieved since the basis for water quality is either absent or inaccurate. Therefore, having a fixed value (or range), like other countries, and possibly, the use of carrying capacity, i.e. considering flushing rate and sedimentation rate of an area as a basis will be more ideal in setting the standard value, rather than a percentage increase, since the detection of an increase in an area will only be accurately measured if enough sampling sites are taken, which in turn, can be very expensive and labor intensive.

Standards for marine water as well as for TDS should also be added as one of the parameters that will be monitored. In oligotrophic areas, it is possible to disregard this parameter since it can be easily taken off by aquatic plants and filter-feeding organism. However, in places characterized by high eutrophication and intensive aquaculture, like in Pangasinan, it is advisable if this can also be considered.

Heavy Metals

Toxic substance refers to any substance, material or disease-causing agent which can cause death, disease, malignancy, genetic mutation or abnormalities upon ingestion, assimilation, exposure or inhalation. Moreover, some effects can be manifested in the offspring. Heavy metals are big concern to aquaculture because of its potential toxic effects and ability bioaccumulate thus resulting to lower product quality and human health risk. Major anthropogenic sources include ore mining and processing, plating industries, smelters, tanneries and textile industries. The concentration of these substances can be determined through chemical analysis of the water, sediments and fish tissue.

Mercury

Mercury (Hg) is toxic to both aquatic life and humans. Inorganic form occurs naturally in rocks and soils. It is being transported to the surface water through erosion and weathering. However, higher concentrations can be found in areas near the industries and agriculture. The most common sources are caustic soda, fossil fuel combustion, paint, pulp and paper, batteries, dental amalgam and bactericides.

There are many cases of death and diseases which were directly related to mercury contamination. The most popular is the Minimata disease which happened in Japan wherein hundreds of people died due to the mercury effluents coming from a vinyl processing plant.

Mercury remains in its inorganic form (which is less toxic) until the environment becomes favorable, i.e. low pH, low dissolved oxygen, and high organic matter) where some of them are converted into methylmercury (the more toxic organic form). Methylmercury tends to accumulate in the fish tissue, thus making the fishes unsafe to eat.

The lethal levels on fish range from 1 mg/L for tilapia, to 30 mg/L for guppies and 2 mg/L for crustacean (*Cyclops abyssorum*) (Mance, 1987).

Lead

Lead (Pb) comes from deposition of exhaust from vehicles in the atmosphere, batteries, waste from lead ore mines, lead smelters and sewage discharge. Its toxicity is dependent on pH level, hardess and alkalinity of the water. The toxic effects on fish is increased at lower pH level, low alkalinity and low solubility in hard water.

Chronic lead toxicity in fish leads to nervous damage which can be determined by the blackening of the fins (Dojlido and Best, 1993). Acute toxicity, on the other hand causes gill damage and suffocation (Svobodova et al., 1993). Table 17 shows Pb maximum tolerable Pb levels on some aquaculture species.

Table 17. Maximum lead (Pb) concentrations per aquaculture species

Species	*Lead concentration*	*Reference*
Salmonids	4.0–8.0 ppb	Svobodová *et al.* 1993
	< 4.0 ppb annual mean; hardness < 50 mg l^{-1}	EC 1979
	< 0.0 ppb annual mean; hardness 50–150 mg l^{-1}	
	< 20.0 ppb annual mean; hardness > 150 mg l^{-1}	
Cyprinids	< 70.0 ppb	Svobodová *et al.* 1993
	< 50.0 ppb annual mean; hardness < 50 mg l^{-1}	EC 1979
	< 25.0 ppb annual mean; hardness 50–150 mg l^{-1}	
	< 250.0 ppb annual mean; hardness 150–250 mg l^{-1}	
Freshwater	< 3.2 ppb	USEPA 1986
Saltwater	< 8.5 ppb	USEPA 1986
	< 5.6 ppb	Maryland 1993
All species	< 20.0 ppb	Meade 1989
Drinking water	< 50.0 ppb	Maryland 1993

Concentrations of lead in (µg/L) seawater from selected countries are given below. This information shows that Scotland and Pakistan contain the lowest concentration of this contaminant. Please take note, however, that this data were compiled in 1999. There may be some changes in the values at present time.

Lead concentrations in seawater in ASEAN and other countries.

Location	**Lead Concentration (µg/L)**	**Reference**
INDONESIA		
Segara Anakan, Central Java	5.7 - 14.8	Romimohtarto et al., 1991
MALAYSIA		
East and west coast, Peninsular Malaysia	0.20 - 0.34	Ismail et al., 1995
Juru Estuary, Penang	2.0 - 2.8	Seng et al., 1987
Straits of Malacca	1.7 - 3	Shazili and Mohamed, 1990
SINGAPORE		
Straits of Johore/ Singapore	0.2 - 0.6	Singapore Ministry of

		Environment, 1993
Coastal sea water (filtered)	0.09 - 0.56	Ang et al., 1989
	0 - 40	Rahman et al., 1980
	1.6 - 3.1	Chai, 1975
Coastal waters	0.3 - 0.8	Tang et al., 1997
THAILAND		
Upper Gulf of Thailand	0.10 - 32.0	Suthanaruk et al., 1995
Upper Gulf of Thailand	0.13 - 12.18	Chumchuchan and Suthanaruk, 1997
Tapi River	0.042-0.479	Hungspreugs et al., 1991
Ban Don Bay	0.003-0.235	
Upper Gulf of Thailand	0.20 - 1.13 (wet season) 0.16 - 1.16 (dry season)	Hungspreugs et al., 1989
Lower Gulf of Thailand	0.01 - 0.06	Hungspreugs et al., 1989
Upper Gulf of Thailand	0.44 (wet season) 0.66 (dry season)	Hungspreugs, 1984
Gulf of Thailand	5.28 - 6.56	Siriruttanachai, 1980
VIETNAM		
Coastal waters	trace - 6.8	Nguyen et al., 1997
Coastal waters	1.0 - 5.1	Pham and Vo, 1997
OTHER COUNTRIES		
Scottish estuary, Scotland	0.006 - 0.16	Hall et al., 1996
Arabian Sea, Pakistan	0.019 - 0.189	Tariq et al., 1993
Alexandria region, Egypt	0.455 - 0.785	Abdel-Moati, 1991
Gove Harbour, Australia	0.15 - 2.87	Peerzada et al., 1990
Thames Estuary, UK	0.025 - 0.4	Harper, 1988

Source: Wong and Tan (AMEQC, 1999)

Cadmium

Cadmium (Cd) is a highly toxic metal. The most common sources are electroplating, nickel plating, smeltling, engraving, batteries, sewage sludge, ferlizers and zinc mines. In fishes, acute toxic exposure results to damage of the central nervous system and parenchymatous organs. Chronic exposure have adverse effects on the reproductive organs, maturation, hatchability and larval development as well as mortality (Svobodova et al., 1993; Lloyd, 1992). Table 18 shows the concentration levels of cadmium in some aquaculture species.

Toxic level is reduced by high concentrations of calcium and carbon dioxide, since these two elements compete with cadmium for binding sites. Thus, cadmium is less toxic in hard water. Due to its binding properties, most cadmium ends up in sediments where its biological availability is limited and thus less toxic.

Cadmium is exceptionally persistent in humans. Low levels of exposure may even result to considerable accumultion especially in kidneys (WHO, 1989). The common pathways of exposure are oysters, clams and some crustaceans.

Table 18. Maximum cadmium (Cd) concentrations per aquaculture species

Species	Concentration (ppb)	Comment	Reference
Salmonids	< 0.2		Svobodová *et al.* 1993
Salmonid hatcheries	< 0.4 < 3.0	Alkalinity < 100 mg l^{-1} Alkalinity > 100 mg l^{-1}	Piper *et al.* 1982
Cyprinids	< 1.0		Svobodová *et al.* 1993
Crustaceans	< 2.0		UNEP 1985
Freshwater	< 1.1		USEPA 1986
Saltwater	< 9.3		USEPA 1986
General guidelines	< 0.5 < 5.0	Alkalinity < 100 mg l^{-1} Alkalinity > 100 mg l^{-1}	Meade 1989
Human drinking water	< 10.0		Maryland 1993

Nickel

Nickel (Ni) is only moderately toxic to fish and has little capacity for bioaccumulation. The dominant form in water is Ni^{2+}. It enters the aquatic environment through the disposal of batteries and effluents from metal plating and ore processing industries.

In humans, nickel can be carcinogenic and teratogenic (Dojlido and Best, 1993).

The table below shows acceptable values for abovementioned heavy metals set by Australia, ASEAN, India, Kenya, New Zealand, Philippines and the United States for freshwater and marine environment. Among the four metals, generally, cadium has the most stringent criteria, ranging from less than 0.2-5.0 µg/L, followed by mercury, lead and then lastly by nickel. The reason for this is that as previously mentioned, cadmium and mercury are highly toxic metals and exceptionally persistent in humans.

Generally, among the countries, standards set by the ASEAN, Australia and New Zealand are the strictest, followed by India for both freshwater and marine environment. The Philippine standards for the four metals are within the mid-range.

It is important to note that the behavior of these metals change depending on the environment. Thus, acceptable levels should be different for both marine and freshwater.

Table 19. General acceptable levels of heavy metals for freshwater and marine environment

Country	Freshwater (µg/L)				Marine (µg/L)				Reference
	Hg	Pb	Cd	Ni	Hg	Pb	Cd	Ni	
Australia	<1.0	<1-7.0	< 0.2-1.8	<100	<1.0	< 1-7.0	< 0.5-5	< 100	ANZECC, 2000
ASEAN					0.16	8.5	10		AMEQC, 1999
India					1.0	1.0	1.0		
Kenya	5.0	10	10	300	5.0	10	10	300	EMCR, 2006
New Zealand	<1.0	<1-7	< 0.2-1.8	<100	<1.0	< 1-7.0	< 0.5-5	< 100	ANZECC, 2000
Philippines	2.0	50	10	NA	2.0	50	10	NA	DAO 1990-34

United States	1.4	65	4.3	470	1.8	210	42	74	EPA

Pesticides

Pesticide refers to any chemical used to control unwanted non-pathogenic organisms, including insecticides, acaricides, herbicides, fungicides, algicides and rotenone (used in killing unwanted fish) (Svobodova, 1993). These chemicals are designed to be toxic and persistent, thus it is also of concern in aquaculture. It can affect the quality of the aquaculture product as well as the health of the fish and humans. Table 20 shows the relative persistence of selected pesticides.

Table 20. Persistence of pesticides

Readily degradable 1/2 life < 2 wks	*Slightly degradable 1/2 life = 2-6 wks*	*Moderately persistent 1/2 life = 6 wks-6 mos.*	*Persistent 1/2 life > 6 mos.*
Captan	Chloramben	Carbofuran	DDT
Carbaryl	Chlorpropham	Carboxin	γ-HCH
Chlorpyrifos	Dalapon	Chlordane	Aldrin
Dichlone	Diazinon	Chlorfenvinfos	Dieldrin
Dicrotophos	Disulfoton	Chloroxuron	Heptachlor
Endotol	Fenuron	Dimethoate	Isodrin
Endosulfan	MCPA	Diphenamid	Monocrotophos
Fenitrothion	Methoxychlor	Diuron	Benomyl
Malathion	Monuron	Ethion	
Methiocarb	Phorate	Fensulfothion	
Methylparathion	Propham	Linuron	
Parathion		Prometion	
Phosphamidon		Propazine	
Propoxur		Simazine	
2,4-D		Toxaphene	

Source: McEwan and Stephenson 1979.

Pesticide can be split into seven main categories namely, inorganic, organophosphorous, carbamates, derivatives of phenoxyacetic acid, urea, pyridinium, and derivatives of triazine (Dojlido and Best, 1993). Among these, the chlorinated form is of particular concern due to its persistence and tendency to bioaccumulate in fish and shellfish. Some examples are dichloro-diphenyl-trichloro-ethane (DDT), aldrin, dieldrin, heptachlor, and chlordane. The most common sources are agricultural run-offs, effluents from pesticide industries and aquaculture farms. Table 21 shows the safe levels of some chlorinated insecticide to aquaculture species.

Table 21. Safe level of some chlorinated hydrocarbons insecticides to aquatic species

Pesticide	Safe level (ppb)
Aldrin	0.003
BHC	4.0 0.08
Chlordane	0.01 0.0043 (freshwater) 0.004 (marine)
DDT	0.001
Dieldrin	0.003 0.0019
Endrin	0.004 0.0023
Heptachlor	0.001

	0.0038 (freshwater) 0.0036 (marine)
Toxaphene	0.005 0.0002

Source: Boyd (1990) and USEPA (1993)

Table 22 shows the different standard values for chlorinated pesticides set by Australia, New Zealand, Philippines and the United States. Among these countries, only Philippines and United States have set the standards for both marine and freshwater aquaculture. Most of the standards in Australia and New Zealand were concentrated only in freshwater operations.

Table 22. Acceptable values of selected pesticides for freshwater and marine environment

	Australia		**New Zealand**		**Philippines**		**United States**	
Pesticides	Freshwater (µg/L)	Marine (µg/L)	Freshwater (µg/L)	Marine (µg/L)	Freshwater (µg/L)	Marine (µg/L)	Freshwater (µg/L)	Marine (µg/L)
Aldrin	< 0.01	ND	< 0.01	ND	1.0	1.0	3.0	1.3
Chlordane	< 0.01	0.004	< 0.01	0.004	3.0		2.4	0.09
DDT	< 0.0015	ND	< 0.0015	ND	50	50	1.1	0.13
Dieldrin	< 0.005	ND	< 0.005	ND	1.0	1.0	0.24	0.71
Endrin	< 0.002	ND	< 0.002	ND	Nil	Nil	0.086	0.037
Heptachlor	< 0.005	ND	< 0.005	ND	Nil	Nil	0.52	0.053
Toxaphene	< 0.002	ND	< 0.002	ND	5.0	5.0	0.73	0.21
Reference	ANZECC, 2000		ANZECC, 2000		DAO 1990-34		USEPA	

ND – not determined (insufficient info)

Generally, the standards on different kinds of chlorinated pesticide vary among countries, being endrin and heptachlor as having the most stringent in the Philippines and United States, while Australia and New Zealand put importance on DDT.

Coliform Bacteria

Coliform bacteria consist of several genera belonging to Family *Enterobacteriaceae*. Fecal coliform which belongs to this group is found mostly in feces and intestinal tracts of humans and other warm blooded animals. It is not pathogenic per se, however, it is a good indicator of the presence of pathogenic bacteria. High levels of fecal coliform in the water may cause typhoid fever, hepatitis, gastroenteritis, dysentery and eat infection.

Some factors which may affect the concentration of this bacteria are the presence of wastewater and septic system, animal wastes, run-off, high temperature and nutrient-rich water. Table 23 shows the level of coliform set by Hongkong, Kenya, Malaysia, Norway, Philippines and the United States.

Table 23. General acceptable levels of faecal and total coliform

Country	Faecal coliform		Total coliform		Reference
	Freshwater (count per 100 ml)	Marine (count per 100 ml)	Freshwater (count per 100 ml)	Marine (count per 100 ml)	
Hongkong				610	EPD
Kenya			30	30	EMCR, 2006

Malaysia	10-100*		100-5,000*		
Norway				100	SFT
Philippines		Nil (MPN)	5,000 (MPN)	70 (MPN)	DAO 1990-34
United States			< 10,000 (CFU)	NA	USEPA

MPN: Most Probable Number
* : Geometric mean
Nil: extremely low concentration, not detected by instrument used
CFU: colony-forming unit

Among the countries, only Malaysia and the Philippines have set a standard exclusively for the presence of fecal coliform, while the rest of the countries set the standard for total coliform. Among these countries, Kenya has the most stringent requirement, i.e. 30 counts per 100 ml for freshwater and marine, followed by the Philippines and Hongkong. The Philippines has a lower required level in the marine waters than in freshwater.

RECOMMENDATIONS

Some recommendations presented here are from the results of a previous project, EMMA (Environmental Monitoring and Modelling of Aquaculture in risk areas of the Philippines) and of consultations with the different sectors, i.e. national agencies, aquaculture feed millers, producers, fish farmers and the academe.

Information Campaign

One problem for low compliance may be due to lack or insufficient information on the effects of pollution to the water environment as well as to the existing laws and guidelines in place. This can be address by including information campaign as part of the water quality monitoring guideline. The religious sector can also be tapped as a medium to transfer the information, as they are proven to be very effective and has power to move the critical mass into action.

Monitoring and Surveillance

Monitoring the compliance and physical monitoring were identified as two critical factors that can ensure the success or failure of the monitoring system in place. The Philippine government has inadequate staff and resources to regularly and religiously monitor all the monitoring stations in the whole country, as well as conduct visits to all the point sources of effluents.

One of the recommendations is the creation of inter-agency body that will be responsible in the monitoring. The composition is important since there are different sectors involved, e.g. industrial effluents, aquaculture wastes, domestic sewage, etc. One agency alone may not have the technical capabilities or equipments. This is also seen as a good mechanism in addressing the problem of insufficient staff and resources. However, emphasis on the composition and the roles and responsibilities of each agency should be laid out clearly, to avoid the overlaps and duplication of efforts. Moreover, a mechanism should also be well-planned to ensure the continuity of the efforts.

Incentive System and Sanctions

The monitoring system implements the polluter's fee, i.e. the violators pay for the pollution that they produce. In addition to that, an incentive system can also be included to encourage the compliance.

One way is the certification program, wherein the industries or aquaculture operators that comply will be awarded a certificate or a seal signifying their compliance. There can also be a reduction on taxes or annual registration fees.

Standards/criteria Protecting the Aquaculture Industry

It is recognized that aquaculture's contribution to food security is significant, and as capture fisheries supply levels off, the demand for fishery products will be supplied by aquaculture. If this is to be realized in the Philippines, special water quality criteria in mariculture zones, especially from effluent from other sources should be in place. As mentioned earlier, the existing standards and criteria are meant to protect the water body in general, and there are no special provisions protecting the aquaculture industry like in other countries such as New Zealand and Australia.

Development of sediment quality standards for the marine environment

Some of the parameters used in determining the water quality, especially in detecting the nutrient level, i.e. ammonia, nitrate, NH_3, etc. are not stable. Moreover, water quality fluctuates constantly depending on the time of day, tide and season. It is also affected by rainfall and sunlight. This makes it difficult to set water quality criteria or standards as the samples may be taken at a time that the standards are met but then may be exceeded soon afterwards. The taking of the samples gives just a snapshot of the conditions at the time of the sampling. Thus, these are not reliable in showing the real condition of the water.

The setting of sediment standards allows a longer time frame to be analysed. Sediments are affected by nutrient inputs especially from aquaculture, but this change takes time to accumulate so the sampling of sediments provides analysis of water quality conditions over a longer time scale. It is therefore recommended to develop sediment quality standards for marine waters of the Philippines as these are more reliable.

Analysis of sediment quality in Bolinao

Bolinao is considered to have the most extensive monitored mariculture activities in Lingayen Gulf. The investigations in this study have focused on the area (Bolinao Bay) between the northeast mainland of Cape Bolinao, Santiago Island and Cabarruyan Island. The bay has three inlets/outlets. The two up in the northern part of the bay are connected strait out to open water. However, the southern entrance is connected to Tambac Bay which also has a lot of aquaculture activity (Please see Figure _). The Tambac Bay was also affected by fish kill episodes. The studied bay are relatively shallow and the average depth in most of the area are less than 6 meters deep.

Sediments are often used as indicators for evaluating the environmental status of an area. It takes much longer time to change the condition of the sediments compared to the water quality parameters. Water quality parameters give a snap shot of the conditions while sediments tell you how the conditions have developed over a longer time period. Therefore are sediment samples very good indicators of the environmental condition.

Sampling was carried out with a 0.05 m^2 modified van Veen grab. The grab had hinged and lockable inspection flaps constructed of 0.5 mm mesh. The upper side of each flap was covered by additional rubber flap allowing water to pass freely through the grab during lowering, yet closing the grab to prevent the sediment surface being disturbed by water currents during hauling. At each station one chemical and one biological grab sample were taken. The volume of the sediment that contained the biological samples was recorded and gently sieved through a 1mm-round hole sieve immersed in sea water. The fauna for the semi-quantitative sample were then preserved in 4% formaldehyde solution stained with rose bengal and neutralized with borax. Each sediment sample was described with respect to sediment type, smell, colour, larger living animals and any other obvious features (e.g. visible organic layer, bacteria, feces, fish food etc.). Further samples were taken for chemical analysis, grain size and fauna analysis.

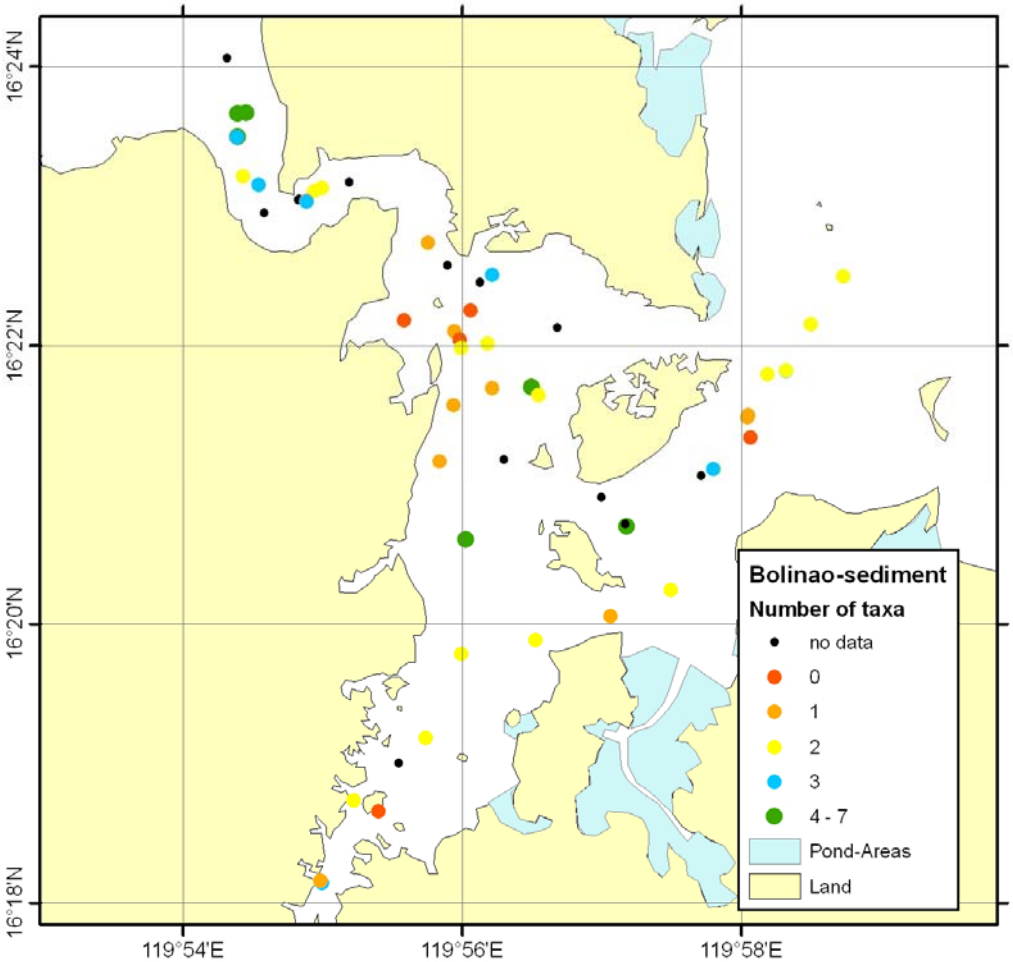

Figure _. Map of Bolinao area showing the sediment conditions

Biological analyses

In the laboratory, the fauna was extracted from the preserved biological samples and sorted into major taxonomic groups. The taxonomic groups were: Polychaeta, Gastropoda, Bivalvia, Amphipoda, Natantia, Nemertini, Brachyura, Balanoida, Ostracoda, Porifera, Sipunculida, Ophuroida, Cnidaria and Fish. Out of the 45 grab samples that were analysed, 9 samples had

4 or more taxa , 8 samples had 3 taxa, 18 samples had only 2 taxa, and 10 samples had only one taxon.

1 taxa per sample had either:	2 taxa per sample included two of listed taxa:	3 taxa per sample included 3 of the listed taxa:	4 – 7 taxa per sample included 4 -7 of the listed taxa:
Gastropoda indet. Bivalvia indet. Polychaeta indet.	Bivalvia indet. Gastropoda indet. Polychaeta indet. Amphipoda indet Ostracoda indet. Balanoida indet	Polychaeta indet. Gastropoda indet. Bivalvia indet. Nemertini indet. Ostracoda indet. Balanoida indet Natantia indet Brachyura indet Amphipoda indet Sipunculida indet	Polychaeta indet. Bivalvia indet. Gastropoda indet. Natantia indet Amphipoda indet Brachyura indet Nemertini indet Balanoida indet Fish Porifera Ophiuroida indet. Cnidaria indet.

Based on the results, the most prominent, abundant or "indicator" taxa were further identified to the lowest feasible taxonomic levels and the approximate abundances noted. The resulting data on faunal distribution and abundance and the occurrence of indicator taxa were used to classify the environmental conditions of the sediment according to the Norwegian Standard for environmental monitoring of marine fish farms (NS 9410). Classification criteria are summarised in Table _.

Table _. Classification of environmental status based on a semi-quantitative fauna analyses (NS 9410).

1 (VERY GOOD)	2 (GOOD)	3 (ACCEPTABLE)	4 (UNACCEPTABLE)
At least 20 taxa. None of the taxa comprising over 65% of the sample	5-19 taxa. More than 20 individuals (except Nematoda). None of the taxa comprising over 90% of the sample	1-4 taxa (except Nematoda)	No animals

Using the Norwegian classification to categorise the sediments of Bolinao, it would mean that out of 45 grab samples analysed, no sampling station had shown VERY GOOD environmental status, i.e. had at least 20 taxa, 9 sampling stations are classified as GOOD (samples had 4 or more taxa), while all the remaining sampling sites are ACCEPTABLE (had between 1 and 4 taxa). These results are consistent with the findings from water quality analyses and turbidity.

It is highly recommended that further work is undertaken to adapt the Norwegian sediment classification scheme for the Philippines.

CONCLUSION

Aquaculture increasingly plays a more significant role in fisheries sector. Together with increasing aquaculture production comes increasing nutrient release into the holding waters with an effect on water column leading to eutrophication. In addition, increasing nutrient output from domestic, industrial, agriculture, deforestation and livestock production also adds to the water nutrient load and these have an effect on aquaculture and carrying capacity of the water body.

Water is the most important resource for aquaculture. It determines the quality of the product as well as the success of the industry. Thus, it is vital for the government to regulate aquaculture and put in place laws that will protect the water environment. Generally, the Philippines have existing regulations related to water quality management. One of these is the DAO 1990-34 which was extensively discussed in this paper. This law can be compared with other countries like United States, Australia and New Zealand. These countries are considered to be well-advanced in managing the aquaculture industry.

Among the criteria discussed in this paper, the Philippines have provisions for almost all except for alkaline level. However, it is important to note that the standard levels for nutrients, e.g. ammonia (ionized and unionized), and nitrite are still lacking. Ammonia is known to contribute to eutrophication thus should be given an emphasis in regulating the water quality.

Generally, in all countries included here, the concept of water quality monitoring is at the micro-level. The sum of all the effluents coming from different sources was not considered, given the fact that there is only one water body that will assimilate all these wastes. Moreover, it is also important to note that not all water body is the same. Some may have a short residence time, i.e. time for the water to flushed out all the nutrients, while some have long residence time. Thus, the pollution level and its effect to the organisms will not be uniform.

Secondly, the regulations do not protect the aquaculture industry per se. Among the countries, only Australia provide for this, by regulating the effluents from sources which drain their wastes into the aquaculture sites. In this way, the industry is protected by protecting its basic requirement – water quality.

Lastly, the basis for the water quality standards should depend on the carrying capacity of the area. There is no mention (it is either it is lacking) on how these numbers are assumed, on which basis where they taken. Therefore, a standard working properly in one country cannot ensure that it will do the same for the Philippines, since carrying-capacity is a summation and a function of many factors. The Philippines cannot just copy from other countries since both are not equally identical – in magnitude, in physical processes, etc.

Although the Philippines have sufficient laws to regulate the water quality, there are some parameters that needed to be revised and added. There are also mechanisms that should be put in place in order to strengthen the effectiveness of the monitoring system. The intensity of aquaculture industry in 1990 when it was drafted is so much different now. Fish kills, algal blooms, intensification of fertilizers were not as popular during that time. Perhaps it is high time to look at these laws again.

Although the Philippines have sufficient laws to regulate the water quality, there are some parameters that need to be revised and/added. The intensity of aquaculture industry in 1990 when it was drafted is so much different now. Fish kills, algal blooms, intensification of fertilizers were not as popular during that time. Perhaps it is high time to look at these laws again.

Summary of water quality standards/criteria relevant to freshwater aquaculture

Parameter	Unit	Australia	Brunei Darussalam	Kenya	Malaysia	New Zealand	Norway/Canada	Philippines	South Australia	United KIngdom	United States	Desirable for fish prod
pH		5.0 - 9.0	6.9	5.0 - 9.0	6.5 - 9.0	5.0 - 9.0	6.5-9.0	6.5 - 8.5	> 6.0	≥ 5.5		6.5-9.0
DO	mg/L	> 5.0			3.0 - 7.0	> 5.0	>6	5.0				> 5.0-6.0
TAN	mg/L				0.3							< 0.01
NH_4	mg/L	< 1.0				< 1.0			0.5			
NH_3	mg/L	< 0.03				< 0.03	1.37		0.01			
NO_3	mg/L	50			7.0	50		10				< 0.5
NO_2	mg/L	0.10			0.40	0.10	0.06					
P	mg/L				0.1 – 0.2		< 0.025	0.05-0.2				
PO_4	mg/L	< 0.10				< 0.10					0.05-0.1	
TSS	mg/L	< 40		30	25-150	< 40	<10%	≤ 30% (increase)	20			
TDS	mg/L			1,200	500-1000							
Faecal coliform	count/ 100 ml				10-100							
Total coliform												
Mercury (Hg)	µg/L	< 1.0		5.0		< 1.0	.01	2.0		1.4		
Lead (Pb)	µg/L	< 1.0-7.0		10		< 1.0-7	1-7	50		65		< 3.2
Cadmium (Cd)	µg/L	<0.2-8		10		<0.2-8	0.2-1.8	10		4.3		< 1.1
Nickel (Ni)	µg/L	< 1000		300		< 1000	25-150			470		
Aldrin	µg/L	< 0.01				< 0.01	.004	1.0			3.0	0.003
Chlordane	µg/L	< 0.01				< 0.01	.006	3.0			2.4	0.0043
DDT	µg/L	< 0.0015				< 0.0015	.001	50			1.1	0.001
Dieldrin	µg/L	< 0.005				< 0.005	.004	1.0			0.24	0.0019
Endrin	µg/L	< 0.002				< 0.002	.0023	Nil			0.086	0.004 0.0023
Heptachlor	µg/L	< 0.005				< 0.005	.01	Nil			0.52	0.0038
Toxaphene	µg/L	< 0.002				< 0.002		5.0			0.73	0.005 0.0002

Summary of water quality standards/criteria relevant to marine water aquaculture

Parameter	Unit	Australia	ASEAN	Hongkong	India	Kenya	Malaysia	New Zealand	Norway	Philippines	Sount Australia	United States	Desirable for fish prod
pH		6.0 - 9.0			6.5 - 8.5		6.5 - 9.0	6.0 - 9.0		6.5 - 8.5			6.5-9.0
DO	mg/L	> 5.0	4.0	≥ 4.0	5.0		3.0 - 7.0	> 5.0		5.0	> 6.0		> 5.0-6.0
TAN	mg/L						0.3						< 0.01
NH_4	mg/L	< 1.0						< 1.0			0.2		
NH_3	mg/L	< 0.01		≤ 0.021				< 0.01			0.05		
NO_3	mg/L	< 100	0.07					< 100					
NO_2	mg/L	< 0.10	0.055					< 0.10					
P	mg/L		0.015						< 0.025				
PO_4	mg/L	<0.05						<0.05		Nil			
TSS	mg/L	< 10	10% increase			30		< 10		≤ 30% (increase)	10		
TDS	mg/L					1,200							
Faecal coliform													
Total coliform													
Mercury (Hg)	µg/L	<1.0	0.16		1.0	5.0		<1.0		2.0		1.8	
Lead (Pb)	µg/L	<1-7.0	8.5		1.0	10		<1-7.0		50		210	< 5.6
Cadmium (Cd)	µg/L	<0.5-5	10		1.0	10		<0.5-5		10		42	< 9.3
Nickel (Ni)	µg/L	< 100				300		< 100				74	
Aldrin	µg/L	ND						ND		1.0			0.003
Chlordane	µg/L	0.004						0.004				1.3	0.004
DDT	µg/L	ND						ND		50		0.09	0.001
Dieldrin	µg/L	ND						ND		1.0		0.13	0.0019
Endrin	µg/L	ND						ND		Nil		0.71	0.004 0.0023
Heptachlor	µg/L	ND						ND		Nil		0.037	0.0036
Toxaphene	µg/L	ND						ND		5.0		0.053	0.005 0.0002

N.D. = not detected

Appendix 1. DENR Usage and Classification for Fresh water

The quality of Philippine waters shall be maintained in a safe and satisfactory condition according to their best usages. For this purpose, all waters shall be classified according to the following beneficial usages:

(a) Fresh Surface Waters (rivers, lakes, reservoirs, etc.)
Classification Beneficial Use 1

Class AA Public Water Supply Class I. This class is intended primarily for waters having watersheds which are uninhabited and otherwise protected and which require only approved disinfection in order to meet the National Standards for Drinking Water (NSDW) of the Philippines.

Class A Public Water Supply Class II. For sources of water supply that will require complete treatment (coagulation, sedimentation, filtration and disinfection) in order to meet the NSDW.

Class B Recreational Water Class I. For primary contact recreation such as bathing, swimming, skin diving, etc. (particularly those designated for tourism purposes).

Class C
1) **Fishery Water** for the propagation and growth of fish and other aquatic resources;
2) **Recreational Water Class II** (Boatings, etc.)
3) **Industrial Water Supply Class I** (For manufacturing processes after treatment).

Class D 1) For agriculture, irrigation, livestock watering, etc.
2) **Industrial Water Supply Class II** (e.g. cooling, etc.)
3) Other inland waters, by their quality, belong to this classification.

Suggested changes to the water usage and classification taking into account the recent developments in aquaculture

(a) Fresh Surface Waters (rivers, lakes, reservoirs, etc.): Classification Beneficial Use 1

Class AA Public Water Supply Class I. This class is intended primarily for waters having watersheds which are uninhabited and otherwise protected and which require only approved disinfection in order to meet the National Standards for Drinking Water (NSDW) of the Philippines.

Class A Public Water Supply Class II. For sources of water supply that will require complete treatment (coagulation, sedimentation, filtration and disinfection) in order to meet the NSDW.

Class B Recreational Water Class I. For primary contact recreation such as bathing, swimming, skin diving, etc. (particularly those designated for tourism purposes). These water shall be of such quality that they are suitable as habitat for fish and other aquatic life. The habitat shall be characterized as free flowing and natural. The aquatic life, dissolved oxygen and bacteria content of Class B waters shall be as naturally occurs in order to ensure spawning and egg incubation of indigenous fish species

Discharges to Class B waters shall not cause adverse impact to aquatic life in that the receiving waters shall be of sufficient quality to support all aquatic species indigenous to the receiving water without detrimental changes in the resident biological community.

Class C

1) **Fishery Water** for the propagation and growth of fish and other aquatic resources; These waters shall be of such quality that they are suitable as habitat for fish and other aquatic life. The habitat shall be characterized as natural. Suitable for breeding, culture of indigenous aquaculture species and should be within the DENR water quality criteria. Discharges to Class C waters may cause some changes to aquatic life, provided that the receiving waters shall be of sufficient quality to support all species of fish indigenous to the receiving waters and maintain the structure and function of the resident biological community.

2) **Recreational Water Class II** (Boatings, etc.)
3) **Industrial Water Supply Class I** (For manufacturing processes after treatment).

Class D 1) For agriculture, irrigation, livestock watering, etc.
2) **Industrial Water Supply Class II** (e.g. cooling, etc.)
3) Other inland waters, by their quality, belong to this classification.

Appendix 2. DENR Water Quality Criteria/Water Usage and Classification for Marine Water

(b) Coastal and Marine Waters: Classification Beneficial Use

Class SA

1) Waters suitable for the propagation, survival and harvesting of shellfish for commercial purposes;
2) Tourist zones and national marine parks and reserves established under Presidential Proclamation No. 1801; existing laws and/or declared as such by appropriate government agency.
3) Coral reef parks and reserves designated by law and concerned authorities.

Class SB

1) **Recreational Water Class I** (Areas regularly used by the public for bathing, swimming, skin diving, etc.);
2) **Fishery Water Class I** (Spawning areas for Chanos chanos or "Bangus" and similar species).

Class SC

1) **Recreational Water Class II** (e.g. boating, etc.);
2) **Fishery Water Class II** (Commercial and sustenance fishing);
3) Marshy and/or mangrove areas declared as fish and wildlife sanctuaries;

Class SD 1) **Industrial Water Supply Class II** (e.g. cooling, etc.);
2) Other coastal and marine waters, by their quality, belong to this classification.
Suggested changes to the water usage and classification taking into account the recent developments in aquaculture

(b) Coastal and Marine Waters: Classification Beneficial Use

Class SA
1) Waters suitable for the propagation, survival and harvesting of shellfish for commercial purposes; Class SA waters shall be of such quality that they are suitable as habitat for fish and other aquatic life. The habitat shall be characterized as free flowing and natural. The aquatic life, dissolved oxygen and bacteria content of Class SA waters shall be as naturally occurs. Class SA waters are suitable for the consumption of shellfish grown in it.

2) Tourist zones and national marine parks and reserves established under Presidential Proclamation No. 1801; existing laws and/or declared as such by appropriate government agency.
3) Coral reef parks and reserves designated by law and concerned authorities.

Class SB
1) **Recreational Water Class I** (Areas regularly used by the public for bathing, swimming, skin diving, etc.);
2) **Fishery Water Class I** (Spawning areas for Chanos chanos or "Bangus" and similar species). These water shall be of such quality that they are suitable as habitat for fish and other aquatic life. The habitat shall be characterized as free flowing and natural and should be within the DENR water quality criteria. The aquatic life, dissolved oxygen and bacteria content of Class SB waters shall be as naturally occurs in order to ensure spawning and egg incubation of indigenous fish species. Class SB waters are suitable for the growing of shellfish but they should be depurated in disinfected water or held in Class SA water for at least 1 week.

Discharges to Class SB waters shall not cause adverse impact to aquatic life in that the receiving waters shall be of sufficient quality to support all aquatic species indigenous to the receiving water without detrimental changes in the resident biological community.

Class SC
1) **Recreational Water Class II** (e.g. boating, etc.);
2) **Fishery Water Class II** (Commercial and sustenance fishing);
3) Marshy and/or mangrove areas declared as fish and wildlife sanctuaries;

Class SD 1) **Industrial Water Supply Class II** (e.g. cooling, etc.);
2) Other coastal and marine waters, by their quality, belong to this classification.

Appendix 3. USA Classification of Freshwaters

1. Class AA waters. Class AA shall be the highest classification and shall be applied to waters which are outstanding natural resources and which should be preserved because of their ecological, social, scenic or recreational importance.

   A. Class AA waters shall be of such quality that they are suitable... as habitat for fish and other aquatic life. The habitat shall be characterized as free flowing and natural.

   B. The aquatic life, dissolved oxygen and bacteria content of Class AA waters shall be as naturally occurs.

2. Class A waters. Class A shall be the 2nd highest classification.

A. Class A waters shall be of such quality that they are suitable...as habitat for fish and other aquatic life. The habitat shall be characterized as natural.

B. ...The aquatic life and bacteria content of Class A waters shall be as naturally occurs.

3. Class B waters. Class B shall be the 3rd highest classification.
   A. Class B waters shall be of such quality that they are suitable... as habitat for fish and other aquatic life. The habitat shall be characterized as unimpaired.
   B. The dissolved oxygen content of Class B waters shall be not less than 7 parts per million or 75% of saturation, whichever is higher, except that for the period from October 1st to May 14th, in order to ensure spawning and egg incubation of indigenous fish species...

   C. Discharges to Class B waters shall not cause adverse impact to aquatic life in that the receiving waters shall be of sufficient quality to support all aquatic species indigenous to the receiving water without detrimental changes in the resident biological community.

4. Class C waters. Class C shall be the 4th highest classification.
   A. Class C waters shall be of such quality that they are suitable...as a habitat for fish and other aquatic life.

   B. The dissolved oxygen content of Class C water may be not less than 5 parts per million or 60% of saturation, whichever is higher, except that in identified salmonid spawning areas where water quality is sufficient to ensure spawning, egg incubation and survival of early life stages, that water quality sufficient for these purposes must be maintained...

   C. Discharges to Class C waters may cause some changes to aquatic life, provided that the receiving waters shall be of sufficient quality to support all species of fish indigenous to the receiving waters and maintain the structure and function of the resident biological community.

(Source: http://www.epa.gov/bioindicators/pdf/Chapt4_WQS_final.pdf)

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