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Guidelines for managing aeration and water quality in fishponds in Bangladesh

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Introduction and objective

The rapid development and intensification of freshwater aquaculture in Bangladesh has resulted in new challenges for managing pondwater quality. Enhancing fish production means a larger fish biomass per unit volume and more decaying organic waste to control. As a result, pond management techniques need to be adapted to maintain optimal water quality parameters. Understanding and managing the oxygen budget in fishponds is essential to optimize production.

The objective of this document is to provide basic information on managing water quality in freshwater fishponds in Bangladesh to support farmers in profitable, sustainable aquaculture practices.

Photo credit: Francois Rajts

Pond aerators ensuring constant adequate dissolved oxygen levels, better growth and preventing mortality by morning oxygen depletions.

1. Pondwater quality requirements and management

Managing and maintaining water quality is essential in aquaculture. It is particularly important in Bangladesh because of the type of ponds used. Because of the country's flat topography, it is not feasible to supply water to ponds using gravity alone. Most of the fishponds, such as dug-out ponds, are deeply excavated either close to or below the underground water table. Water in these ponds is sourced in three ways: (1) from the underground water table through percolation, (2) rainfall or (3) pumping water from either boreholes or surface water. Pumping is the only way to drain these kinds of ponds. As a result, adding or exchanging water quickly cannot solve water quality problems, like it can in ponds supplied and drained using gravity.

It is necessary to maintain proper water quality parameters and apply appropriate interventions as required. Monitoring water quality using expensive analysis kits is not always feasible in small farms, but simple observation of ponds in the early morning and late afternoon can identify water quality problems. Some low-cost water analysis kits, designed for use in the ornamental fish trade, can be used to monitor ponds.

1.1. Effects of pond soil on water quality

The quality of water in a fishpond largely depends on soil quality. Interactions between water and pond soil influences the salinity, pH, alkalinity, hardness and turbidity of the water. Using the following techniques can improve and maintain the quality of the soil:

- Apply agricultural lime (1 t/ha) or hydrated lime (0.5 t/ha) during pond preparation. This improves soil structure, reduces turbidity and increases pH.
- Remove excess organic sediment.
- Dry and then either plough or till the pond bottom.

Ponds made on a beel frequently have high turbidity, particularly those with low alkalinity and hardness. The preferred range for turbidity is 25–80 mg/L.

The following is a list of turbidity issues and management options:

- Excess turbidity limits the sunlight that penetrates into ponds. This can negatively impact the photosynthetic production of small microscopic plants called phytoplankton and cause physical damage to fish gills.
- If pond dikes are not well protected from erosion, this will increase turbidity. Maintaining protective grass on the slopes and the top of the pond can limit erosion.
- In ponds with existing turbidity problems, common carp should not exceed 10% of the stock, as their burrowing stirs sedimentation.
- Filling ponds with hard water from groundwater is preferable, because this helps settle colloidal clay particles.
- To fix excess turbidity, apply agricultural gypsum at 500 kg/ha to settle the particles.

1.2. Water depth in ponds

Water depth can influence water quality. In deep ponds, thermal stratification can occur. Stratification can affect light penetration and adequate aeration of the lower pond levels and the pond floor. Under anoxic conditions, the formation of toxic gases in the soil on the pond floor can lead to poor water quality. Implications for pond management are as follows:

- The recommended water depth for nursery ponds is 1–1.5 m and 1.5–1.8 m for grow-out ponds.
- Maintain a full water level in ponds during fish culture.
- Install a water depth gauge to monitor water levels.
- Insufficient water depth has negative effects on the pond ecosystem:
    - The temperature can rise during the daytime and drop as low as 13°C in the winter.
    - Low water levels promote the development of filamentous algae.
    - Living aquatic organisms consume more oxygen in overheated water, leaving morning dissolved oxygen (DO) levels low.

    - The total amount of DO in the pond drops.
    - There is increased toxicity of ammonia, hydrogen sulfide and other toxic elements.
    - There is a higher risk of predation by birds. Installing a small mesh can protect the pond from birds.
- Ponds with a depth of more than 1.8 m frequently have anaerobic layers at the bottom because of thermal stratification.
- If it is likely there is an anoxic layer at the bottom of the pond, use a venturi aerator or air lifts using pressurized air to break the stratification by forced circulation.

1.3. Water quality parameters

The most important water quality parameters to monitor in freshwater fishponds are pH, DO, temperature, total ammonia nitrogen (TAN) and transparency. The values presented in Table 1 indicate the preferred values and dangers related to extreme conditions.

1.3.1. Temperature

Radiation from the sun heats pondwater. As a result, the water temperature is usually highest in late afternoon. In shallow ponds, the whole water column can reach dangerously high temperatures for fish. In ponds that are deep enough, daytime thermal stratification occurs, and fish can swim to deeper and colder layers. Plankton populations can similarly shelter in the lower layers. Consequently, the upper layer of water is heated up more than in ponds having transparent water. Maintaining good plankton bloom is important. The upper and lower layers tend to mix during the night when the surface layer cools down, destratifying the pond. Wind is important in preventing thermal stratification, but high vegetation on dikes can block the wind, resulting in stratified ponds. Sheltering plankton in ponds, coupled with stratification, can result in anoxic conditions at bottom of the pond.

1.3.2. pH

The pH in ponds fluctuates throughout the day. It is generally lowest in the morning due to higher levels of carbon dioxide released by respiration and highest in afternoon because free carbon dioxide is used for photosynthesis. The level of fluctuation is governed by the intensity of photosynthesis and the amount of carbon dioxide produced by living aquatic organisms and chemical reactions in the pond.

The interaction between pH and alkalinity results in limited pH fluctuation because of the buffering effect of bicarbonates in the pondwater. Applying agricultural lime can increase pondwater alkalinity. The pH level strongly influences ammonia toxicity. At pH 7, for example, TAN is toxic to carps at or above a concentration of 9 ppm. But at pH 9, TAN can be lethal at only 1 ppm (Table 5).

Parameters	Allowed	Ideal	Danger	Remark on danger
pH	6.5	7.5–8.5	>9	Ammonia toxicity increases
DO (mg/L)	>2	4–10	<2	Risk of suffocation temperature and free carbon dioxide dependent
Water temperature (°C)	>15	25–30	>30 summer <15 winter	Risk in shallow water in both winter and summer
TAN (mg/L)	1	0.8–1	>1	Toxicity is dependent on pH, temperature, species and size
Transparency (Secchi disk cm)	20	25–30	<20 and >30	Excess plankton can die off, resulting in morning low DO and hypoxia. Low density plankton can result in starvation

Source: modified after Boyd 1998a.

Table 1. Most important water quality parameters for carp pond culture.

1.3.3. Dissolved oxygen

DO concentration is probably the most important parameter that influences the health of aquatic organisms in ponds (Table 2).

The DO level in ponds fluctuates throughout the day. During the daytime, the photosynthesis of phytoplankton increases the DO, so the DO level is usually highest in late afternoon. At night, in the absence of photosynthesis, oxygen produced during the daytime and stored in the water is the main source of oxygen for living organisms. In addition, a limited quantity of oxygen enters the water through diffusion from the atmosphere. Accordingly, the level of DO declines during the night and is lowest in the early morning. Fish are at the greatest risk of suffocation during this time, particularly in shallow ponds because the total quantity of oxygen reserves is lower than in deep ponds, even if both have the same DO level in the evening. This difference can be further enhanced as benthic plants are often better developed in shallow ponds and consume more oxygen at night. To maintain appropriate DO levels in ponds, farmers should follow these protocols:

- Avoid overstocking and overfeeding, as decomposing feces and wasted feed both consume oxygen.
- Pay special attention to sudden changes in the weather, reduced sunlight or clouds, and strong winds.
- If it is possible to predict the morning's DO level the previous evening, then farmers can prepare for emergency aeration.
- Temperature, salinity and atmospheric pressure drive the saturation level of DO. Hot water holds less oxygen than cold water, and fish consume more oxygen in hotter water. The saturation point of oxygen in relation to temperature is presented in Table 3. During hot weather, pay special attention to prevent low early morning DO levels.
- Clear submerged and floating aquatic weeds from the pond, except those maintained for dike protection. Weeds will affect oxygen consumption at night.
- Make sure that vegetation on dikes does not block sunlight from entering the pond and does not block the wind from blowing across the surface of the water.
- Maintain a full water level during the culture period.
- Keep aeration devices, such as paddlewheels and venturi aerators, ready for operation at all times, because they can maintain appropriate DO levels.
- Low DO usually occurs in the early morning. It is frequently associated with high carbon dioxide in the water, which can kill fish. To remove carbon dioxide, refer to Section 1.5.

1.3.3.1. Solubility of oxygen in the water

There is an equilibrium between oxygen (and other gases) in the air and in the water. In the absence of oxygen-producers and consumers, the equilibrium remain stable in a given constant environment. This is called the saturation point. The solubility of oxygen in freshwater is shown in Table 3.

Several factors influence the solubility of oxygen, but in the freshwater fishponds of Bangladesh it is generally enough to consider only the water temperature because the land elevation is close to sea level.

Dissolved oxygen (mg/L)	Effect
< 0.5	Small fish can survive brief exposure.
0.5–1.5	Most species will die of exposure after a few hours or days.
1.5–5	Most species will survive, but stress, greater susceptibility to disease and slow growth can occur.
> 5	This is the desirable concentration.

Source: Boyd 2001.

Table 2. Common effects of DO concentration on warm-water fish.

Temperature °C	**Oxygen solubility mg/L**	**Temperature °C**	**Oxygen solubility mg/L**
10	11.29	21	8.92
11	11.03	22	8.74
12	10.78	23	8.58
13	10.54	24	8.42
14	10.31	25	8.26
15	10.08	26	8.11
16	9.87	27	7.97
17	9.67	28	7.83
18	9.47	29	7.69
19	9.28	30	7.56
20	9.09	35	6.93

Source: Boyd 2011.

Table 3. Saturation point of DO in freshwater at normal sea level atmospheric pressure at different temperatures.

1.3.3.2. Sources of oxygen in pondwater

There are two ways that oxygen gets into the water: either through absorption from the air, or through photosynthesis, mainly from phytoplankton. Aerators are artificial sources of oxygen in pondwater (Section 2).

1.3.3.2.1. Diffusion from air to water

Diffusion from the air into the water is a slow process, except when the wind is blowing strongly and forming waves. The daily oxygen intake from the atmosphere through diffusion is approximately 1.5 g/m^2 in small ponds and 4.8 g/m^2 in big ponds, where the wind action is stronger (Kepenyes and Váradi 1983). The rate of oxygen transfer between air and water depends on three factors: the amount of turbulence, the ratio of surface area to water volume, and the level of oxygen concentration in the water.

At low levels of DO, diffusion is faster than at a level close to saturation. The implication for farmers is to plan aeration hours when the oxygen transfer is highest and avoid using aerators when the rate of transfer is low, except for mixing oversaturated upper layers with bottom layers.

In rivers, the main source of oxygen is diffusion from the atmosphere. This is because the plankton density is poor and the flowing/agitated water surface is what allows oxygen to penetrate the pond. As a result, the DO level in rivers is usually at the saturation point. This is an important factor for rearing river-spawning fish, particularly for silver carp, catla and rohu. The pond should have a high DO level at all times to optimize growth, appetite, feed conversion and gonadal development among the fish and to increase their resistance to diseases. In Bangladeshi ponds, diffusion from the atmosphere is low because of the type of ponds. Most ponds are not the drainable dug-out type. They have high dikes, and the water level is located 5–6 feet below the top of the dikes. High dikes restrict the wind, which limits the mixing and stirring of the water. In addition, the size of the ponds are rather small and most dikes are planted with trees, which screens the ponds from the wind. The exception to this are large ghers, which are made on rice fields and have low dikes.

Loss of oxygen through diffusion from water to air occurs during afternoon hours. At this time of day, the surface layer of pondwater gets oversaturated through photosynthesis, while the DO levels drop in the deeper layers due to thermal stratification. As a result, farmers should pay close attention to the following:

- Take note of the dominant wind direction during pond construction to maximize the effect of wind on pond circulation and aeration.
- Clear pond dikes of high vegetation to allow the water to circulate and the wind to generate waves.
- Use an adapted aerator to mix oxygen-rich water into the deep layers of the pond, or use airlifts to mix the layers.
- Other oversaturated gases also escape from the water through diffusion. Applying aeration is also useful to reduce hydrogen sulphide and ammonia concentrations.

1.3.3.2.2. Species adaptation for using surface layer during low DO

When morning DO levels remain low for a long time,[1] some species can develop an extended lower lip with high density blood vessels (Rajts 2014) (Plate 1). It helps the species to better use the tiny upper layer of water, which has a higher oxygen content than lower zones.

1.3.3.2.3. Oxygen production by photosynthesis

In intensified aquaculture ponds, where the fish biomass is much higher than in natural waters, the main source of oxygen is the enhanced phytoplankton population grown through fertilization.

In ponds 1.2 m to 1.8 m in depth, the phytoplankton produce most of the oxygen. If a pond is shallow, and/or low in plant nutrients (from poor fertilization), the water can become transparent and the benthic algae on the pond floor will produce most of the oxygen. However, benthic algae does not generate as much zooplankton as phytoplankton does, and harmful filamentous algae also develop well in shallow water. As such, farmers should maintain an appropriate water depth in their ponds and use a Secchi disk to monitor transparency. A Secchi disk depth of 25–30 cm is recommended. Farmers can use this as a guide for fertilization to maintain a good phytoplankton density.

On sunny days, oxygen production is higher, because the rate of photosynthesis is related to light intensity and quality. That is why it is recommended to clear the dikes of trees to allow the pond to receive full sunlight.

Photo credit: Francois Rajts

Photo credit: Francois Rajts

Extended lower lip of *tambaqui* in a badly managed pond in Guyana.

Extended lower lip of silver carp in the polluted Gulshan Lake, Bangladesh.

Plate 1. Response of some fish species to persistent low DO content in water.

1.3.3.3. Factors influencing dissolved oxygen in pondwater

1.3.3.3.1. Physicochemical factors

The oxygen content of pondwater rarely reaches the saturation point. It is constantly changing, depending on several factors. Temperature is a strongly influencing factor. As temperature increases, the saturation point decreases, so less oxygen can stay in hot water than in cold (Table 3). When the water temperature increases 10°C, fish consume double the amount of oxygen (Berka 1986), while water temperatures over 32°C can lead to low DO levels. Other physiochemical factors include the following:

- Atmospheric pressure: The solubility of oxygen in water is directly related to atmospheric pressure—the higher the pressure, the lower the solubility of oxygen. In the Gangetic Delta, the atmospheric pressure is about 760 mm, because land elevation is almost at sea level, so here the variation of atmospheric pressure is not important.
- Salinity: This is not a significant factor in freshwater ponds in Bangladesh.
- Wind (diffusion through agitation and circulation): refer to Section 1.3.2.2.1.
- Aeration: This increases the DO content of water. The proportion of oxygen in the mixture of gases in contact with the water influences the saturation point. This is why fish bags can be filled with oxygen to maintain high oxygen levels in the water during transportation.
- Water-air interface and water turbulence: Oxygen molecules enter the water from the air. In the absence of wind, the stagnant interface between the water and air is quickly saturated with oxygen. This stagnant saturated surface layer prevents further oxygen diffusion into the pondwater. Yet just a few millimeters below it, the level of DO can be lethally low for fish. That is why fish gather and gasp at the surface of water during the morning when hypoxia is possible. When there is turbulent mixing of the pondwater, the oversaturated top layer is mixed with the DO-deficient lower layers instead of diffusing into the air. As a result, the total quantity of DO in the pond increases and helps prevent low DO levels in the morning.

1.3.3.3.2. Biochemical factors

During the daytime, phytoplankton produce oxygen through photosynthesis. Yet all living organisms in the pond use oxygen at night, including insects, fish, bacteria and phytoplankton. As a result, oxygen levels can drop very low in the early morning, which can result in fish gasping at the surface of the water and even dying. Early indicators and risk factors for morning low DO include the following: a phytoplankton bloom (Secchi disk measurement less than 20 cm), a high stocking rate, a high feeding rate and overfeeding (wasting feed), and sudden weather changes.

Sudden changes in sunlight, rain and storms can all affect DO levels in the morning. After long periods of sunny days, a sudden reduction of light can kill some or most of the phytoplankton population, because it will have adapted to the sunny conditions. On top of this, decomposing dead algae can use up all the available oxygen in the water. If this occurs, it will take a few days for new phytoplankton to grow, so low DO levels in the morning will persist for few days.

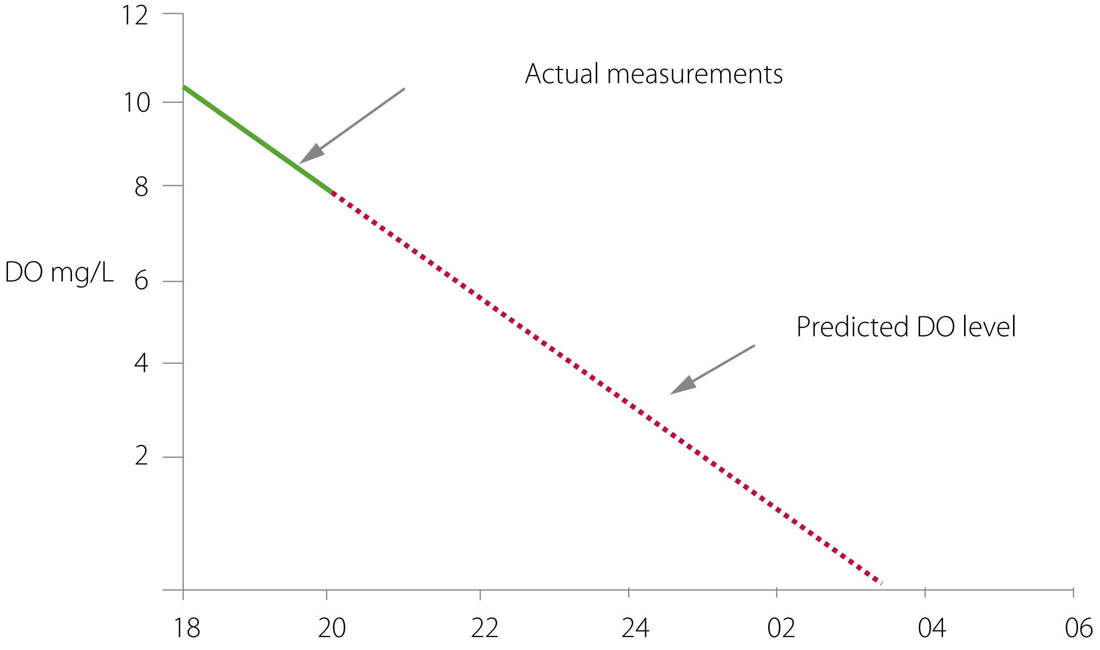
Rain and storms can also both affect morning DO levels. A drop in water temperature from rain will destroy thermal stratification, while mixing up the anoxic bottom layers could result in low DO levels in the morning. In addition, storms mix up the anoxic bottom layer and organic sediment, which can also result in low DO levels in the morning.

It is useful to feed fish about 09:00 to allow better digestion when the DO content of the water is high. Alternatively, farmers can feed their fish twice a day, dividing the daily feed ration so that 60% is given in the morning and 40% in the afternoon.

(See section 1.6 for how to fix low morning DO levels.)

1.3.3.4. Predicting DO concentration at dawn

A simple graphical technique can help predict DO concentration at dawn from measurements taken at dusk. The DO concentration values measured after sunset and 2–3 hours later are used to estimate the linear decline of DO, with respect to time. This technique allows farmers to predict the morning DO situation about 6–7 hours in advance. This is useful during risky days, especially following a plankton crash (Figure 1).



Source: Boyd et al. 1978.

Figure 1. Predicting DO levels, an example of an extreme case.

1.3.4. Preventing low DO concentrations

The following are the management procedures for preventing low DO concentrations in ponds:

- Dry out the bottom between crops and apply lime to enhance organic matter decomposition.
- In ponds without aeration, maintain Secchi disk visibility above 25 cm.
- Use moderate stocking and feeding rates.
- Select and manage good-quality feeds.
- Apply fertilizers in moderate amounts and only when needed to promote plankton blooms.
- Apply adequate aeration in semi-intensive or intensive fishponds.
- Maintain a full water level.
- Check water quality parameters regularly.

1.3.5. Ammonia

TAN toxicity depends on the pH and temperature of pondwater, because it can come in two different forms (Table 4). Un-ionized ammonia toxicity is about 100 times more toxic to fish than ionized ammonia. The value found using a TAN test needs to be calculated to find its toxic un-ionized fraction (Table 4).

Carps can tolerate more TAN than some other species. However, it can be toxic to carps if the concentration is greater than 1 ppm at a pH that is 9 or higher.

In cases of low DO, high levels of ammonia can potentially increase fish deaths. Ammonia can accumulate in pondwater from high fish densities or inappropriate feeding or fertilization. In cases of ammonia intoxication, the fish appear at the surface of the water and display a disorder of the nervous system by jumping out of the water.

An ammonia problem can usually be differentiated from low DO. Low DO is typically seen early in the morning, while ammonia toxicity usually occurs in the afternoon, when both pH and temperature are at their highest.

(See section 1.5 for instructions on how to fix cases of TAN above 1 mg/L.)

1.4. Monitoring and managing water quality parameters

Some water quality parameters can be measured less frequently. These include hardness, alkalinity, carbon dioxide, hydrogen sulphide, phosphorus and nitrite. Table 5 shows the appropriate values of less frequently measured water parameters.

Fraction of toxic un-ionized ammonia in aqueous solutions at different pH values and temperatures. Calculated from data in Emerson et al. (1975). To determine the amount of un-ionized ammonia present, get the fraction of ammonia that is in the un-ionized form for a specific pH and temperature from the table. Multiply this fraction by the total ammonia nitrogen present in a sample to get the concentration in ppm (mg/L) of toxic (un-ionized) ammonia.

	Temperatures (°C)												
pH	6	8	10	12	14	16	18	20	22	24	26	28	30
7.0	.0013	.0016	.0018	.0022	.0025	.0029	.0034	.0039	.0046	.0052	.0060	.0069	.0080
7.2	.0021	.0025	.0029	.0034	.0040	.0046	.0054	.0062	.0072	.0083	.0096	.0110	.0126
7.4	.0034	.0040	.0046	.0054	.0063	.0073	.0085	.0098	.0114	.0131	.0150	.0173	.0198
7.6	.0053	.0063	.0073	.0086	.0100	.0116	.0134	.0155	.0179	.0206	.0236	.0271	.0310
7.8	.0084	.0099	.0116	.0135	.0157	.0182	.0211	.0244	.0281	.0322	.0370	.0423	.0482
8.0	.0133	.0156	.0182	.0212	.0247	.0286	.0330	.0381	.0438	.0502	.0574	.0654	.0743
8.2	.0210	.0245	.0286	.0332	.0385	.0445	.0514	.0590	.0676	.0772	.0880	.0998	.1129
8.4	.0328	.0383	.0445	.0517	.0597	.0688	.0790	.0904	.1031	.1171	.1326	.1495	.1678
8.6	.0510	.0593	.0688	.0795	.0914	.1048	.1197	.1361	.1541	.1737	.1950	.2178	.2422
8.8	.0785	.0909	.1048	.1204	.1376	.1566	.1773	.1998	.2241	.2500	.2774	.3062	.3362
9.0	.1190	.1368	.1565	.1782	.2018	.2273	.2546	.2836	.3140	.3456	.3783	.4116	.4453
9.2	.1763	.2008	.2273	.2558	.2861	.3180	.3512	.3855	.4204	.4557	.4909	.5258	.5599
9.4	.2533	.2847	.3180	.3526	.3884	.4249	.4618	.4985	.5348	.5702	.6045	.6373	.6685
9.6	.3496	.3868	.4249	.4633	.5016	.5394	.5762	.6117	.6456	.6777	.7078	.7358	.7617
9.8	.4600	.5000	.5394	.5778	.6147	.6499	.6831	.7140	.7428	.7692	.7933	.8153	.8351
10.0	.5745	.6131	.6498	.6844	.7166	.7463	.7735	.7983	.8207	.8408	.8588	.8749	.8892
10.2	.6815	.7152	.7463	.7746	.8003	.8234	.8441	.8625	.8788	.8933	.9060	.9173	.9271

Source: Emerson et al. 1975. In Durborow et al. 1997. SRAC Publication No. 463.

Table 4. Percentage of un-ionized toxic ammonia at different temperatures and pH.

Alkalinity and hardness

Measuring hardness and alkalinity is done at the beginning of a culture period. Both can be increased if their values are insufficient, which can happen if rainwater fills the pond or if the pH of the soil is low. If this occurs, farmers should fill the pond with water from a borehole and then apply agricultural lime. To increase alkalinity/hardness, 1000 kg/ha or more of agricultural lime (calcium carbonate in pulverized form) is required.

Carbon dioxide

Carbon dioxide is the basis of photosynthesis, so its presence is particularly important in pondwater. Its concentration fluctuates daily. It is highest in the morning, from respiration overnight, and lowest in the afternoon, because plants and some microorganisms use it for photosynthesis. In afternoon, it is a limiting factor for photosynthesis, if no more free carbon dioxide remains. In this case, the phytoplankton start to remove carbon dioxide from bicarbonates. As a result, the pH can reach dangerous levels. Alkalinity reduces excess pH swings—the higher the alkalinity, the lesser the rate of change in pH. The lower the alkalinity, the greater the possible pH change.

If the pond has a heavy phytoplankton bloom and low alkalinity, then the change in pH from early morning to late afternoon can be quite high—in some situations, as much as 4–5 pH units. In cases such as these, fish can die from the high pH but are more likely to die from other pH-related problems, such as high un-ionized ammonia.

During low DO conditions after a plankton crash, a high concentration of carbon dioxide can be lethal to fish because it prevents the release of metabolic carbon dioxide through the gills and restricts the ability of blood to carry oxygen to tissues. The solution is to use potassium permanganate and/or hydrated lime (Section 1.6).

Nitrite

Nitrite is an intermediate molecule produced during oxidation of ammonia nitrogen to nitrate by nitrifying bacteria. It is considerably more toxic than the nitrate, because it reduces the ability of blood to transport oxygen.

There are two remedies for high nitrite concentration: (1) exchanging or adding fresh water and (2) aeration. High DO levels increase the nitrite tolerance of carps. Nitrobacter (aerobic nitrification bacteria) need oxygen to transform nitrite into nitrate. Using appropriate aerators to circulate the water also improves DO levels at the bottom of the pondwater and promotes the activity of nitrification bacteria there.

Hydrogen sulphide

Hydrogen sulphide is highly toxic to aquatic animals. The 96-hour lethal concentration 50 (LC50) values for hydrogen sulphide to freshwater fish species is in the range of 20–50 µg/L, and much lower concentrations stress the fish and make them more susceptible to disease. Microorganisms produce hydrogen sulphide

Parameters	Allowed	Ideal	Danger	Remarks/Risks
Alkalinity mg/L EQUIV $CaCO_3$	50	80–300	<50	High pH swings, low productivity
Hardness mg/L EQUIV $CaCO_3$	40	100–400	<40	Low productivity
CO_2 (morning) mg/L	15	6–10	>40	Excess amount occurs after a plankton crash, counteracting oxygen absorption, which can be lethal
Hydrogen sulphide H_2S mg/L	0	0	0	pH dependent
Nitrite	0.5	0.2	>0.5	Brown blood disease, suffocation, gill lesions, oedema
Phosphorus mg/L as P_2O_5		0.1–0.5	≥1	Excess phytoplankton bloom, especially blue-green algae

Source: modified after Boyd 1998a.

Table 5. Occasionally monitored water quality parameters.

under anoxic and acidic conditions, and excess mud at the bottom of the pond promotes its formation when coupled with an anoxic lower layer of the pondwater. It can accumulate in undisturbed mud deep at the bottom of the pond up to a concentration of 100 mg/L (Boyd 2014).

The following are the procedures farmers should use to control hydrogen sulphide in their ponds:

- Pay particular attention to sudden weather changes, such as lower atmospheric pressure or a storm, when hydrogen sulphide can escape from the mud and result in fish deaths.
- In a crisis situation, treat the pondwater with potassium permanganate at a rate of 2 mg/L to help oxidize the hydrogen sulphide (Plate 2).
- Feed the fish carefully to avoid wasted feed accumulating on the pond bottom.
- Lime the pond soil properly during pond preparation.
- Every month, drag a rake (*harra*) along the bottom of the pond to liberate gas accumulated in the mud. This should only be done when the DO content of the water is high. Simultaneous aeration will make the operation safer.
- Use an aerator regularly to provide water currents. This provides a flow of oxygenated water across the soil-water interface and prevents thermal stratification of the water. In shallow ponds, however, thermal stratification allows fish to escape from extremely hot surface water, so using aerators in shallow ponds should be done with caution during the hot season.


Photo credit: Francois Rajts

Plate 2. Using potassium permanganate to treat pondwater.

Phosphorus

Phosphorus is a limiting factor for the photosynthesis of phytoplankton. The required concentration of phosphorus in pondwater is 0.1–0.5 mg/L as P_2O_5. Phosphate ions not absorbed by phytoplankton can be absorbed rapidly by the bottom soil. That is why it is suggested to use TSP almost daily in ponds.

Phosphorus locked in mud on the pond bottom can be released back into the water following the next pond preparation. Using lime during pond preparation helps mineralize organic matter in the sediment and improves the texture of the bottom. Tilling or ploughing the dried pond bottom also helps with mineralization. This allows water to penetrate the soil and promote the exchange of nutrients. Ponds should be allowed to dry between crops to ensure aerobic conditions and sediment mineralization.

1.5. Collecting water samples

Water samples should be taken at specific times: at sunrise, when DO levels are at their lowest, and then at around 15:00–16:00 in the afternoon, when they are highest. Water samples should be taken below the surface, because the upper few centimeters of water can be overheated or contain either decreased or increased quantity of dissolved gases compared to the rest of the pond. For DO sample collection using the Winkler method (HACH kit), water should be taken from both the deeper and surface zones.

Additional water quality testing is required for an algal bloom, phytoplankton crash, a sudden weather change, unusual behavior of fish or an outbreak of disease. The suggested frequency of water quality testing is summarized in Table 6.

1.6. Emergency interventions

Carps can suffocate if DO in ponds drops below 1 mg/L. The following are urgent interventions required to remedy a shortage of DO:

- Start aeration as soon as possible.
- Add fresh water. If using water from a borehole, aerate it before adding to the pond because borehole water lacks oxygen and contains carbon dioxide.
- If morning hypoxia results from a plankton crash, apply 2 mg/L of potassium permanganate to help oxidize the suspended dead algae, which will reduce the use of oxygen from the water. Morning hypoxia is also associated with high carbon dioxide, which interferes with the oxygen absorption of fish. To reduce free carbon dioxide, apply liquid hydrated lime. Sprayed it evenly on the surface of the water at a rate of 50 kg/ha for ponds that are 1 m deep. An alternative type of lime to use would be quick lime, which comes in the form of stones. These should be powdered before application by spreading water over them. The quick lime will react with the water to form hydrated lime. Farmers should also stop feeding their fish until new phytoplankton develops and DO levels normalize.

If TAN is greater than 1 ppm in pondwater, carps cannot release the metabolic ammonia produced by their gills. This will seriously damage the fish. The following are the urgent interventions required to avoid mortalities:

- Flush the pond with fresh, clean water to reduce the amount of suspended decaying organic matter and lower excess plankton.
- Use an aerator, paddlewheel, venturi tube (Figures 5 and 8) or something similar to increase the DO level. Aeration will improve DO at the bottom of the pond and provide a favorable environment for nitrifying bacteria to use ammonia.
- Add molasses (200 g/decimal) to the water floor to improve the carbon: nitrogen (C/N) ratio, which is required for heterotrophic bacteria using ammonia.

Frequent measurement		**Occasional measurement**	
Parameters	**Frequency/time**	**Parameters**	**Frequency/time**
pH	Weekly (06:00 and 15:00)	Alkalinity	After filling the pond
DO	Every 3–4 days (06:00 and 15:00)	Hardness	After filling the pond
Water temperature	Every 3–4 days (06:00 and 15:00)	Carbon dioxide	During a plankton crash (morning)
TAN	Weekly (15:00)	Hydrogen sulphide	If there is a foul smell and fish are gasping; not likely in *Talbaria* (morning)
Transparency (Secchi disk)	Weekly (between 12:00 and 15:00)	Phosphorus as P_2O_5	In case of a poor fertilization result

Table 6. Recommended frequency of important water quality measurements.

2. Pond aeration

The natural supply of oxygen is not always sufficient to meet the requirements of fishponds. Changes in DO in pondwater can result in fish stress, poor growth and mortality. The remedy is to use aerators to provide an artificial supply of oxygen. There are many different designs of aerators, which have varying costs and results. Choosing the right type of aerator depends on the structure of the pond, including depth, area and the type of culture planned.

2.1. The importance of pond aeration

Pond aeration is important because it provides appropriate oxygen levels for cultured fish to meet normal metabolic demand. In baors, beels, haors and other natural waters, the oxygen supply that comes from phytoplankton, vegetation and diffusion from the atmosphere is greater than what the fish population needs in a day. In aquaculture ponds, however, the high density of fish, plankton and decomposing wastes requires more oxygen for the given water area than in natural conditions. In intensifying semi-intensive culture, natural sources are not always able to meet the oxygen demand of pond biota, and there is the risk that just one phytoplankton crash could kill the entire fish production.

Investigations into the environmental effects on the metabolic rate of fish have demonstrated that the level of ambient oxygen exerts the greatest effect on fish metabolism. Padmavathy et al. (2002) demonstrated the negative effect of low oxygen concentrations on the metabolism of two Indian major carp species, mrigal (*Cirrhinus mrigala*) and rohu (*Labeo rohita*). Oxygen consumption for both was tested in freshwater between 29°C and 31°C under different oxygen concentrations. Under hypoxic conditions, it was found that both species are oxy-conformers, having significantly reduced their oxygen consumption. At the same time, ammonia secretion significantly increased. Oxygen consumption as an index of total energy use and the ammonia quotient (the ratio of ammonia excreted to oxygen consumed) as an index of protein metabolism indicated changes of protein metabolism in both species under low DO conditions.

The mean values of oxygen consumption and ammonia excretion under normoxic and hypoxic conditions are given in Table 7.

Species	Parameters	Normoxic condition (mean values ± S.E)	Hypoxic condition (mean values ± S.E)
Mrigal carp**	Ambient oxygen (mg/L)	4.55 ± 0.05	1.75 ± 0.05
	Oxygen consumption (ml/kg/hr)	295.12 ± 3.40	92.68 ± 1.91
	NH_3 excretion (ml/kg/hr)	11.41 ± 0.18	18.24 ± 0.34
	Ammonia quotient ****	0.0411 ± 0.0007	0.2207 ± 0.005
Rohu ***	Ambient oxygen (mg/L)	4.88 ± 0.04	1.68 ± 0.04
	Oxygen consumption (ml/kg/hr)	297.16 ± 3.10	104.40 ± 2.40
	NH_3 excretion (ml/kg/hr)	12.15 ± 0.16	18.45 ± 0.30
	Ammonia quotient	0.0471 ± 0.001	0.2107 ± 0.004

Source: extracted from Padmavathy 2002.

** Temperature: 30 ± 1°C. Fish were starved for 24 hours prior to the experiment.*

*** Total length 16.9 ± 1.5 cm and average weight 38.7 ± 4.9 g.*

**** Total length 17.4 ± 1.5 cm and average weight 41.8 ± 6.0 g.*

***** Ratio of ammonia excreted to oxygen consumed.*

Table 7. The mean values of respiratory parameters for mrigal and rohu fingerlings under normoxia and hypoxia in freshwater.*

Fish stressed by frequent low DO will not eat and grow well. Aeration allows higher stocking densities and feeding rates, which reduce water quality problems and maximize production and profit from fish culture.

2.2. Principles of pondwater aeration

In natural conditions, oxygen enters the pond from the air through diffusion. However, once the top layer reaches the saturation point no more oxygen can enter the pond without water circulation. When wind blows across the pond, the waves that it generates increase the interface area for diffusion to take place, which allows more oxygen to enter the water. In addition, wind mixes the top layer of the water with the deeper parts of the pond, which allows oxygen diffusion to continue for a longer period. Diffusion can also occur in the opposite direction if the water becomes oversaturated through photosynthesis, which can lead to a loss of oxygen. Aquaculture pond aerators also increase the air-water interface either by introducing air under the water or spraying water above the surface. Both increase the surface area for diffusion to take place and thus increase DO levels in the water (Boyd 1998; Tucker 2006).

2.2.1. Importance of water circulation

The difference of partial pressure between the actual oxygen content of the water and air is what directs the velocity of gas exchange. In diffusion, the rate of oxygen transfer from the air is higher when the DO level in the water is low, and it slows down as it reaches the saturation point, where it stops altogether. For oversaturated water, the transfer goes in the opposite direction. During afternoon hours, ponds lose surplus oxygen because the surface of the water is generally oversaturated with oxygen. Oxygen escapes into the atmosphere through the water-air interface either by diffusion or from bubbles that, when big enough, come to the surface from the substrate of the pond and escape into the air. This can be observed when touching floating filamentous algae on sunny days. On the other hand, the DO level can become extremely low or even anoxic in the lower layers of the water. Because of thermal stratification, the upper hot and oxygen-rich water does not mix with the colder (heavier) layers (Wurts 2013). As a result, the daily fluctuation of DO is almost restricted to the upper layers, while the bottom layers remain anoxic all the time.

The remedy for this is to circulate the water from top to bottom. Mixing the saturated upper layer with the DO-poor deeper layers can increase the quantity of oxygen stored in the pond, ensuring higher DO reserves for consumption at night. This should be done in the afternoon when the DO content of the upper layer is highest.

Mixing stagnant layers of water creates the following advantages:

- When water circulation mixes the oxygen-enriched surface water with oxygen-depleted water, it increases the oxygen input from air diffusion.
- Mixing the upper and bottom layers through circulation also drops the temperature of surface water lower than if it remained stagnant. This raises the saturation point of the upper layer, which delays oversaturation and allows the upper layer to absorb more oxygen.
- Carbon dioxide and water are the main nutrients for phytoplankton. Through photosynthesis, phytoplankton use energy from sunlight to produce oxygen and sugar. Along with carbon dioxide and water, algal cells require other nutrients for metabolic functioning. The lack of any nutrients acts as a limiting factor, which reduces the rate of photosynthesis or stops it altogether.
- In pondwater stratification, phytoplankton use up the nutrients in the upper layers and photosynthesis is reduced. By mixing up the thermal stratification, circulating nutrients from the bottom area of the pond ensures a constant supply of nutrients for the phytoplankton to continue producing oxygen.
- A lack of phosphorus is another limiting factor for photosynthesis. Pond soil holds a high amount of phosphorus accumulated through sedimentation from previous batches of culture. Circulation carries aerated water to the bottom and in the presence of oxygen some phosphorus dissolves in the water, helping to support photosynthesis.

2.3. Aeration systems

A range of power sources is used to power aeration devices, including electricity, petrol, diesel, wind and solar. Different types of aerators have different impacts on the pond ecosystem. When choosing which type of aerator to use, whether a surface aerator or an air diffusion aerator, farmers must take several factors into consideration.

With surface aerators (e.g. paddlewheel and vertical pump), water layers below the aerated surface area can remain anoxic depending on the number and size of aerators used and the depth of the pond. If the aerator is placed in the center of a treated spherical area, this could result in little or no water circulation.

Air diffusion aerators, such as venturi tubes and air diffusers, can both aerate and circulate the water. A horizontally configured venturi aerator can mix the pondwater, while air diffusers can circulate the water vertically from the bottom to the pond surface, which impacts the pond soil as well. These types of aerators can also aerate the bottom layers of the pond.

Some aerated ponds have many features in common with rivers, such as reduced daily fluctuation of DO and horizontal water circulation. Sometimes, river spawning species can reproduce in such ponds under these conditions.

Aerators can also be used to address low DO emergencies in ponds, or for continuous aeration to improve DO levels.

Aerator performance

There are two ways to assess how well an aerator is working. The standard oxygen transfer rate (SOTR) is the amount of oxygen added to water in 1 hour under a standard set of conditions. The units of SOTR are pounds of oxygen per hour, which can be multiplied by 0.45 to derive the metric equivalent in kilograms of oxygen per hour. Standard aeration efficiency (SAE) is the standard oxygen transfer rate divided by the power requirement in horsepower. Units of SAE are pounds of O_2/hp per hour, which can be multiplied by 0.61 to derive the SAE in metric units of kilograms of O_2/kW per hour (Boyd 1998).


Photo credit: Francois Rajts

A venturi aerator significantly improved water quality and made year-round reproduction of several fish species possible in hatcheries in Jashore District.

2.3.1. Types of aerators

2.3.1.1. Farm-made emergency aerator

Emergency aerators can be made from a pump and a simple short delivery pipe with a reduced end. This greatly increases the water velocity, resulting in a water jet. It can be deployed quickly in an emergency, such as low morning DO. It does not aerate the whole pond, but it does improve oxygen diffusion into the water. Fish will concentrate in and around the area of increased DO and survive (Plate 3).

2.3.1.2. Paddlewheel aerators

Paddlewheel aerators (Plate 4) are surface aerators supported by floats. These can be powered by electricity or diesel. When dealing with electricity near water, it is imperative to take special care to avoid electrocution. These aerators can be expensive, so some farmers make their own homemade versions (Plate 3). This type of aerator has the highest oxygen input capacity, with an SAE around 1 kg of O_2/kW per hour. However, in deep ponds, as in carp broodstock ponds, it can have trouble mixing the thermal stratification totally, so the bottom layers could remain anoxic. The oxygen intake of paddlewheel aerators is shown in Table 8.

Photo credit: Francois Rajts

Fish concentrating in the aerated zone of the pond, which is surrounded by trees.

Plate 3. Farm-made emergency aerator.

Photo credit: Francois Rajts

Electrical driven.

Photo credit: Francois Rajts

Artisanal, diesel driven.

Plate 4. Paddlewheel aerators.

Average oxygen production (kg/h)	Power input (kW)	Specific oxygen intake (kg/kWh)
1.8	1.98	0.91
1.5	1.6	0.94
2.2	1.56	1.41
2.5	2.56	0.98
3.1	2.56	1.21

Source: extracted from (Kepenyes and Váradi 1983).

Table 8. Oxygen intake of different types of paddlewheel aerators.

2.3.1.3. Vertical pump aerators

Vertical pump aerators are surface aerators (Plate 5). A propeller lifts the water into the air and spreads it around the device. It does not circulate the water. Instead, it is used in shallow ponds for intensive culture of trout and tilapia. In deep ponds, as in some carp ponds, it can have trouble mixing the thermal stratification totally, so the bottom layers could remain anoxic. This type of aerator is not recommended for semi-intensive carp culture.

2.3.1.4. Air diffusers

Air diffuser aerators consist of an air pump or blower and perforated plastic pipelines fixed on the pond bottom to distribute the air. The perforation is usually about 1 mm in diameter, providing 5–10 mm bubbles (Plate 6). Smaller holes can be blocked by decomposing algae. The pipeline has a main line that is connected to distributor secondary and tertiary lines. The diameter of the pipes in each line is reduced to allow similar air pressure at every spot.

When the air is diffused through a perforated pipe, it forms large bubbles up to 10 mm in diameter. As the bubbles emerge and rise up to the surface, part of their oxygen content dissolves in the water. This generates upward movement in the water and creates a mixing effect.

The smaller the bubbles, the larger the surface area of the water-air interface, resulting in more oxygen diffusion into the water. The longer the bubbles remain in the water column, the more oxygen that diffuses. Since small bubbles rise more slowly than large ones, they diffuse more oxygen. The deeper the water column, the longer it takes for the bubbles to reach the surface.

This type of aerator requires a lot of power because of the high amount of energy required for air pumps/blowers to sufficiently compress air and the high quantity of air required. In addition, the SAE greatly increases with the distance needed for air bubbles to reach the water surface, so in deep ponds more oxygen can be dissolved from the same quantity of air. However, many aquaculture ponds are shallow, so the air bubbles escape quickly, resulting in lower oxygen diffusion (Table 9).

Plate 5. Vertical pump aerator is practical for standby emergency operations too.

Plate 6. An air diffuser pond/tank aerator in operation.

Water depth (m)	Working parameters		Average oxygen intake (kg/h)	Power input (kW)	Specific oxygen intake (kg/kWh)
	mmHg	m3/h			
0.8	135	512	2.7	9.4	0.29
0.8	120	410	2.4	7.5	0.32
1.2	135	312	3.0	5.9	0.51
1.2	120		1.9	4.05	0.47

Source: extracted from (Kepenyes and Váradi 1983).

Table 9. Example of oxygen intake using an air diffuser aerator.

This type of aerator thoroughly mixes pondwater, as the compressed air enters the pond at the bottom. It has mainly been used in the flock system for shrimp culture or in the flock system for indoor culture, which has recently started in Bangladesh. However, it is not recommended for semi-intensive carp culture because its requires so much power and causes difficulties for sampling/harvesting operations.

Showing the force of an aerator water jet made out of material from a local plumbing shop: 4 inches in diameter, 50 m3/h capacity, operated by a 4 hp diesel engine or a 2 kW/h electrical motor.

Creating a deep current to reduce thermal stratification while improving DO throughout the entire pond.

Plate 7. Venturi aerator made during the AIN project.

2.3.1.5. Venturi aerators

A venturi aerator is a device mainly used to aerate and mix water in fishponds, lagoons and wastewater treatment. The function of the aerator is based on the increased speed of pumped water inside the injector (Bernoulli's principle). Its oxygen production capacity is lower than the paddlewheel surface aerator, but it has other advantages. It improves the oxygen budget of ponds by increasing the quantity of oxygen stored in the pondwater through destratification. It also improves the aerobic decomposition of organic matter in the pond soil/sediment.

The SAE of venturi aerators was tested under WorldFish's Aquaculture for Income and Nutrition (AIN) project in 2012 (Table 10 and Plate 7). The estimated SAE was 0.45 kg of O_2/kWh. However, the SAE was likely higher because of the increased oxygen consumption of fish, as well as other biota. The speed of water circulation measured on the shoreline was 12 cm per second when the venturi aerator was operated. This type of aerator is recommended for ponds over 1.5 m deep.

2.4. Oxygen budget of the pond ecosystem

Phytoplankton consume oxygen at night, but during the daytime its oxygen production exceeds consumption. If there is excessive bloom, however, the sheltering effect of a high density of phytoplankton could kill off the phytoplankton in sheltered layers, which translates into additional oxygen consumption.

The oxygen consumption of zooplankton remains constant day and night. However, dangerous situations can arise when excess zooplankton eat up all the phytoplankton, resulting in anoxia. If this happens, continuous aeration is recommended until the phytoplankton develop. That is why it is important to rigorously maintain fertilization using Secchi disk readings.

The DO demand of the pond bottom varies according to the quantity of decomposing organic wastes (much higher at higher feeding) and the consumption by the benthos. In ponds 1 m deep, the oxygen consumption of the pond bottom over a 24-hour period changes between 1 and 3 mg/L (Kepenyes and Váradi 1983). Boyd 2018 demonstrated an example of the oxygen budget of a fishpond (Table12).

Period of aerator operation hours	Pond area for one big ha (1333 m^2)	Volume of water (m^3)	Fish biomass (kg)	DO at 07:00 (mg/L)		Velocity of circulating water current at shoreline (cm/sec)
				At 50 cm depth	At bottom (1.80 m)	
Non-operated	1	2400	450	2	0.5	No water circulation
23:00–07:00	1	2400	450	4.5	3.5	12 cm/s

Table 10. Venturi aerator testing under the AIN project in 2012.

Species	Advanced fry	Fingerlings	Advanced fingerlings
Catla	634 ± 9	565 ± 27	516 ± 30
Rohu	549 ± 26	459 ± 41	374 ± 40
Mrigal	532 ± 24	449 ± 28	343 ± 32

Source: after Mohapatra et al. 2017.

Table 11. Oxygen consumption of advanced fry, fingerlings and advanced fingerlings of Indian major carps (mg/kg/h).

Budget component	Oxygen available or required (kg/ha/night)
Available oxygen: diffusion from the air	10
Available oxygen: water column at dusk	100
Oxygen demand for respiration: fish	60
Oxygen demand for respiration: organisms in sediment	42
Oxygen demand for respiration: water column (plankton)	120
Oxygen required from mechanical aeration	112
Total available oxygen	110
Total oxygen demand for respiration	222
Oxygen required from mechanical aeration	112

Source: Boyd 2018.

Table 12. Typical nighttime oxygen budget for a 1 ha catfish pond.

The oxygen consumption of carps in a pond under semi-intensive culture is only a fraction of the daily oxygen demand of the pond. Benthos, plankton and decaying organic wastes are the main consumers, which sometimes results in morning anoxia. Mohapatra (2017) found an inverse relation between the development stage and the oxygen consumption of fingerlings of Indian major carps. Catla is by far the highest oxygen consumer, followed by rohu and mrigal (Table 11). The lower critical tolerance limits of oxygen in water for the survival of advanced fingerlings were 0.4 mg/L for catla and 0.32 for both rohu and mrigal (Table 11).

2.5. The benefits of using aerators in aquaculture ponds

The benefits of using pond aerators include the following:

- improves the survival of cultured fish
- improves the oxygen budget of a pond by increasing the quantity of oxygen stored in the pondwater through destratification
- produces better pond soil by accelerating the mineralization of organic sediment
- mixes the pondwater well so that the entire pond area is available to fish
- increases fish stocking and feeding rates
- provides good fish health, better feed conversion, better growth rate and higher profit
- increases natural food due to a better environment for zooplankton development.

2.6. How to select the best aerator

To choose the best aeration device for a pond, farmers should consider several factors: cost-effectiveness, performance of the aerator (SAE), fish species, culture intensity, how much of the pond is sheltered by trees, pond size, water depth, dike slope and soil quality.

The following is a list of issues farmers should consider before purchasing an aerator:

- For semi-intensive carp culture, continuous aeration is not recommended. Gasoline or diesel-operated models are acceptable.
- To increase DO in the water, the SAE capacity of an aerator (kilograms of O_2/kWh) should be adapted to the estimated oxygen demand of the pond.
- The durability of aerators varies widely, depending on the quality standards of the company that makes them and the materials used.
- If aerators are positioned poorly, they can erode dikes and the pond bottom. Paddlewheel aerators can also create holes up to 1 m deep at the bottom.
- Dikes with steep slopes are prone to erosion from the current created by aerators. Covering the pond slopes using geotextiles can protect them.
- For water depths 1.5 m or less, using a paddlewheel or another surface aerator is suggested.
- For ponds deeper than 1.5 m, a venturi aerator is recommended.
- Continuous aeration to provide the greatest possible production is less profitable than moderate aeration to improve water quality and enhance feed conversion efficiency (Boyd 1998b).

Note

[1] Rajts, personal observation on silver carp population in the polluted Gulshan Lake and on Tambaqui (*Colossoma macropomum*) in badly managed ponds in Guyana.

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