
# Guidelines for managing aeration and water quality in fish hatcheries and nurseries in Bangladesh

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# Introduction and objective

In Bangladesh, induced breeding of cultured species in hatcheries is essential for supplying quality fish seed to the aquaculture industry. Following the decline of overexploited natural stocks, the availability of natural spawn has also declined in rivers. By 2018, driven by increasing demand, 825 private hatcheries had been developed in the country, and these hatcheries accounted for 6668 t of fish seed produced (DOF 2018). This quantity of hatchlings was generated despite poor survival rates for fry during nursing and transportation, which is characteristic of fish production in Bangladesh. To address these problems, hatcheries need to adopt improved techniques to manage water quality, including adequate oxygenation of hatcheries and nursery ponds and better management of other parameters.

The objective of this document is to guide hatchery owners and nursery farmers in water quality management to improve the survival and quality of fish seed produced.


Fish concentrating in the aerated zone.

# 1. Managing water supply in hatcheries

Among the major freshwater species farmed in Bangladesh are major Indian carps, Chinese carps and silver barbs. All are river spawners that require consistently high oxygen levels in the water. Major river systems, including the Ganges, Brahmaputra, Mekong, Yangtze and Amur, are the natural habitat for most of the fish species reproduced in Bangladesh's hatcheries. Unlike many farm ponds, however, the amount of dissolved oxygen (DO) in river waters is always high, with no significant day-night fluctuations in DO levels. In these natural conditions, dissolved carbon dioxide levels are low, at about 5 mg/L. For successful reproduction in hatcheries, the water should have more or less similar physiochemical characteristics to that of the original habitat of the species being cultured. There is an urgent need to improve water quality management practices in both hatcheries and nurseries to better replicate natural conditions.

The water supply for freshwater hatcheries in Bangladesh is provided by tube wells, which pump water from depths of 50–150 m below ground. This has the advantage of providing clean water that is free of pathogens and has a constant temperature of about 27°C. The quality of this water is generally good. However, because it is pumped from a deep underground aquifer, it contains no DO, the carbon dioxide level is high and it frequently has dissolved iron.

## 1.1. Negative effects of low quality water in hatcheries and how to remedy them

### 1.1.1. Low dissolved oxygen levels

In the 1980s, many development projects developed and demonstrated hatcheries that included water aeration systems, which treated the water prior to it reaching the hatchery reservoir. However, many private hatchery owners did not adopt the use of aeration towers, because some oxygen is absorbed into the water when it is pumped directly from a borehole and falls into the reservoir. However, DO levels in such hatcheries without aeration devices vary in saturation between 20% and 40%. The amount of DO in the water of these hatcheries depends on the height the water falls from into the reservoir and on the amount of time the water remains in the reservoir. The saturation point of oxygen in water depends mainly on temperature, so other factors are negligible under climatic conditions in Bangladesh (Table 1).

In broodstock treatment tanks, the low DO level of the reservoir water is further increased, because the reservoir is filled continuously by sprinkling, which provides some aeration. This is why breeding is successful in some hatcheries working with DO and carbon dioxide problems. However, egg incubation is often unsatisfactory. Fertilized eggs have difficulty in embryonic development under conditions of low oxygen and high carbon dioxide. The hatching rate of fertilized eggs is poor, and those that do hatch tend to be lethargic, small and typically contain a high percentage of deformed hatchlings. In addition, premature hatching of larvae can occur, because high carbon dioxide levels stimulate the secretion of protease enzymes, which dissolve the egg membrane. Usually the fertilized eggs are kept in incubators, maintained in water directly from the reservoir, without further aeration. As a result, eggs of Indian major carps are able to develop, though the percentage of deformed larvae is high. Such conditions support some production of hatchlings, but their quality is negatively affected. This is most frequently observed in some species that have a higher demand for well-oxygenated water. Eggs of Chinese carps, catla and a minor Indian carp, locally called *bhagna* (*Cirrhinus reba*), are more seriously affected. The eggs of silver carp have a very low survival rate in poorly aerated water. Among hatcheries in Jashore and Barishal, most private hatcheries have developed aeration devices following training and support in 2012 from the joint Aquaculture for Income and Nutrition project of WorldFish and the United States Agency for International Development. As of 2020, most hatcheries and fingerling conditioning centers elsewhere in the country still do not use aeration systems.

| 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 |

**Table 1**. Saturation point of DO in freshwater (sea level atmospheric pressure).

The following practices help raise DO levels in hatcheries:

- To ensure the water in the reservoir tank is saturated automatically, install an aeration tower. WorldFish's design consists of a series of perforated platforms that allow the water to fall, as from a shower, from the upper platform to the lower ones. The size of the holes on the platforms allow the water to flow at 2.5–3 L per minute. For safety, prepare 20% more holes, because leaves as well as other deposits and rust can clog the holes. A design for an aeration tower is shown in Annex 1.
- For a broodstock treatment tank, maintain the DO content of the water by continuously spraying the water at a rate of 1.5–2 L per minute for each kilogram of broodstock in the tank.
- In case the water supply system fails, keep a standby oxygen cylinder with diffuser pipes and a manometer to provide oxygen to the tanks.
- To achieve good results, maintain a DO level of at least 5 mg/L for incubators of eggs or larvae. Measure the DO level at the water outlet of the incubator.

### 1.1.2. High carbon dioxide in water from boreholes

High carbon dioxide in hatchery water is harmful. The recommended level is 5–15 mg/L. Among hatcheries without a sufficient aeration system, if hatchlings are transported more than 4 hours, significant mortalities are likely. This occurs because excess carbon dioxide in the water prevents the blood from carrying oxygen and inhibits fish (and their eggs) from releasing their own metabolic gases. Although hatchlings are packed for transportation in polyethylene bags under pure oxygen, excess carbon dioxide in the water can still kill the fish.

The presence of excess carbon dioxide in hatchery water can be checked by shaking a test tube full of water while measuring the pH. If the level of carbon dioxide is high, the pH value will increase after about 30 seconds of shaking. To get an exact measurement, use the titration method with a water analysis kit (Figure 1). An aeration tower with four stages generally provides a DO level close to 100%, while removing carbon dioxide is more difficult. If the carbon dioxide in the reservoir remains higher than 15 mg/L, then more perforated platforms should be added to the aeration tower (Figure 2).

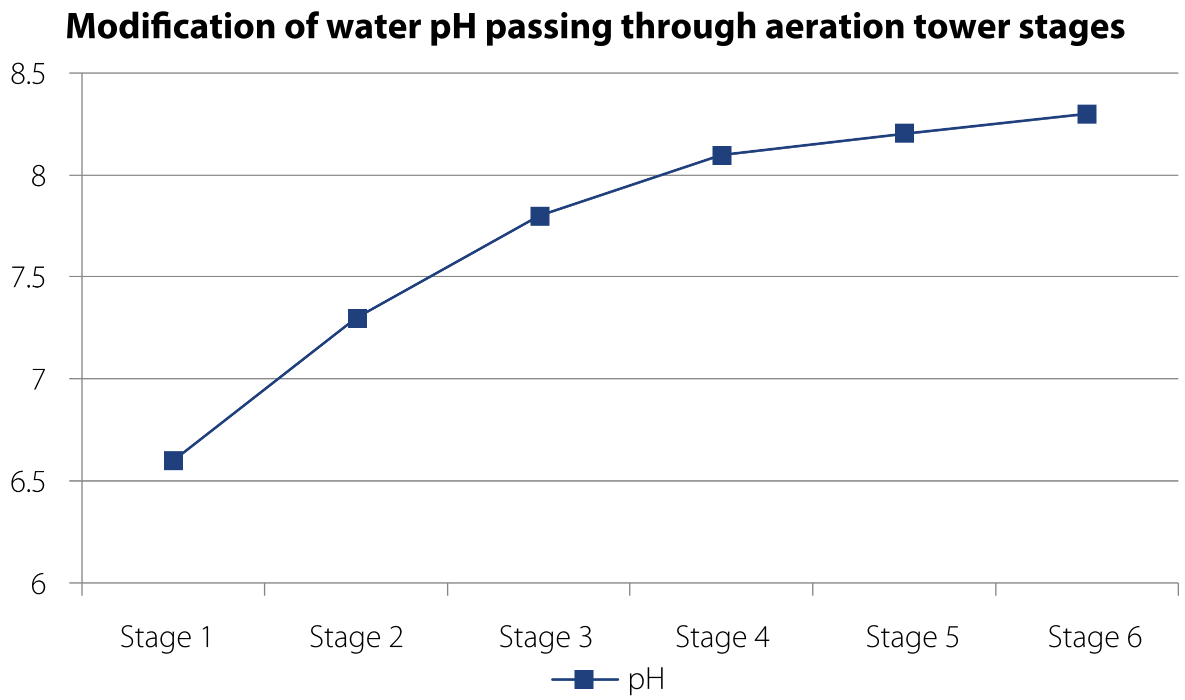



**Figure 1**. Increased pH levels after an aeration tower removes carbon dioxide.

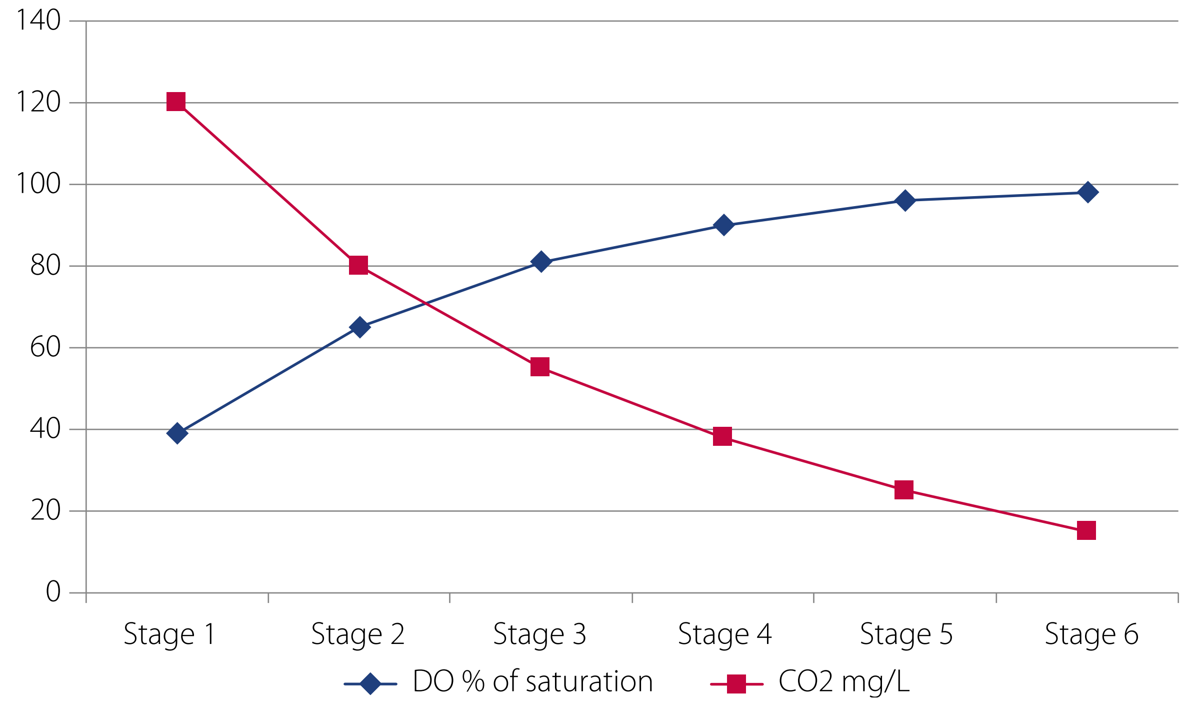



**Figure 2**. Concentration of dissolved gases passing through a six-stage aeration tower.

### 1.1.3. Iron

The iron content of anoxic water from a borehole is harmful for hatcheries. As soon as the water is aerated, the dissolved iron reacts with oxygen. Iron oxide is not soluble in water, and it precipitates in a feather-like form. Its sedimentation is slow due to its special form of crystallization. Iron oxide is harmful to fish because it attaches to larvae and gills, promoting iron bacteria "colonies" that can clog pipelines. Iron bacteria that thrive under high iron concentrations are also harmful to fish eggs under incubation.

It is best not to use borewater that is high in iron. Before installing a tube well, test the borehole to see if the water is free of iron. If iron-free water cannot be found, dissolved iron levels up to 1 mg/L are acceptable.

Filtration can remove suspended iron oxide, but it is expensive and requires backwashing every few hours of operation. Instead, store the water in a pond or tank prior to pumping it into the hatchery reservoir:

- Leave the water in the pond or tank for at least 2 days to allow sedimentation of the iron.
- Keep water hyacinth on half of the surface of the water to prevent the water from overheating and to absorb plant nutrients and reduce plankton production.
- Add fresh borehole water into the reservoir if the water in the pond or tanks becomes too hot. This will add iron as well, but the concentration will be diluted. Make sure the concentration remains under harmful levels.
- To prevent the entrance of copepods, filter water pumped from a pond to the hatchery reservoir via an aeration tower through a 300 µ mesh hapa.

One mg/L of ionic iron removes 0.5 mg/L of oxygen by oxidation.

### 1.1.4. Temperature of the reservoir

The temperature of water from an aquifer situated at the depth of the borehole strainer is approximately equal to the yearly average temperature of the area. In Bangladesh, this is about 27°C, give or take a degree, which is good for most freshwater fish bred in the country. However, water in reservoirs can sometimes exceed 32°C or even drop below 20°C in the cold season, particularly if the water stays there for a long time without being used or refilled. Both high heat and low heat can impact hatching and survival of freshwater fish.

Excess temperatures accelerate the metabolism of embryos and fish, including oxygen demand. As a result, the vertebral column can have a smaller number of vertebrae, which shortens the length of the fish. The sex ratio of tilapia is modified in favor of males at high temperatures.

The following practices help maintain proper water temperatures in hatcheries:

- Cover the water reservoir with a roof.
- The roof should allow the air circulate freely and should have at least one opening to accommodate the aeration tower.
- Water that is stored for a long time in the reservoir can increase in temperature. During hot periods, fill the reservoir just before the start of hatchery operation to avoid overheating.

## 1.2. The benefits of aerators and problems of aeration

There are many benefits to using aeration to ensure appropriate water quality in hatcheries:

- In broodstock ponds, diurnal fluctuations in DO are reduced and environmental conditions more closely resemble the environment of a river. This is favorable for gonadal development, because migration to spawning grounds in rivers is done under similar conditions. Breeding can begin earlier in the year and in some private hatcheries, reproduction of Chinese carps can be done year-round.
- The rate of hatching increases and the frequency of larval deformities decreases.
- Using aeration to successfully remove carbon dioxide from the hatchery water supply lowers the numbers of deaths and can even stop them altogether when hatchlings are transported over long distances in polyethylene bags.
- Production efficiency will increase. In one hatchery, for example, production increased from about 1 kg of hatchlings per 6 kg of female broodfish to 1 kg of hatchlings per 5.3 kg of female broodfish after installing a tower. This translated into a higher gross income of BDT 4.28 million (approximately USD 8500) following the installation of the tower, and profit as a proportion of operating cost almost doubled from 18.5% to 36.7% (Annex 2).

Annex 2 shows the annual operating costs and returns for a hatchery before and after installing an aeration tower.

# 2. Water quality and aeration in freshwater fish nursery ponds

## 2.1. Water depth in ponds

The natural nursery grounds for most freshwater fish in Bangladesh are shallow, seasonally inundated floodplains. In permanent deep water, the composition of plankton is unfavorable for juvenile production. As such, the water depth of nursery ponds should be about 0.6–1 m initially, then increased gradually to 1.2–1.5 m. In shallow ponds, the following management practices are recommended:

- During hot days, increase the depth of the water depth to prevent the water from overheating.
- The oxygen reserve at night is lower per unit of area in shallow waters than in deep waters. Having a standby paddlewheel aerator is recommended for increasing the DO content during periods such as sudden weather changes and early morning low oxygen levels in ponds.
- Adjust the immersion depth and/or speed of the paddlewheel in a shallow nursery pond to minimize water turbidity and erosion of pond walls.

## 2.2. Water quality for plankton management in nursery ponds

Water quality is important for plankton management, particularly in nurseries. This includes ensuring appropriate DO levels and nutrients for plankton development and maintenance. Nursery ponds are stocked with hatchlings carried from hatcheries and sometimes with hatchlings collected from natural sources. The size of hatchlings is about 8 mm, and they require small natural food. The hatchlings adapt to natural feeds during their first month of life. As they grow, their preferred natural feed progresses in order of size from protozoa, to rotifer, nauplii of copepods, small moina, then adult copepods, daphnia and insect larvae.

There are several reasons why young carps need natural food:

- They need the enzymes from the zooplankton for digestion. Artificial feed can be applied as supplementary, preferably from the age of 5 to 6 days old.
- During the first month of life, fry only take food from a water column, since they are unable to feed from the bottom.
- Unicellular phytoplankton is preferred to promote zooplankton growth. Continuous inorganic fertilizing will tend to shelter the pond bottom and control the development of unwanted filamentous algae.
- Fertilizing is guided by water transparency and other water quality parameters, such as pH, total ammonia nitrogen (TAN) and alkalinity.

## 2.3. Water quality parameters in nursery ponds

The most important water quality parameters required are hydrogen ion concentration (pH), DO, temperature, TAN, alkalinity and transparency. Table 2 shows the required values of these parameters and the dangers of excess concentrations.

### 2.3.1. Temperature

As radiation from the sun heats the pondwater, late afternoon is when the water temperature is highest.

### 2.3.2. Hydrogen ion concentration (pH)

The pH in a pond fluctuates during the day. It is generally lowest in the morning due to higher levels of carbon dioxide released by respiration, and then highest in the afternoon when free carbon dioxide is used for photosynthesis. Interaction between pH and alkalinity results in limited pH fluctuations due to the buffering effect of bicarbonates in pondwater. Alkalinity should be higher than 40 mg/L, and it can be increased by applying agricultural lime at a rate of 500 kg/ha. The pH strongly influences ammonia toxicity. For example, at a pH of 7.0 TAN is toxic to carps at a concentration of 9 ppm or higher, but a pH of 9.0 TAN might be lethal at only 1 ppm (Table 5).

### 2.3.3. Dissolved oxygen

The importance of DO concentration is probably the most important parameter influencing the well-being of aquatic organisms, as shown in Table 3.

| Parameters | Allowed | Ideal | Danger | Remark on danger |
|---|---|---|---|---|
| pH | 6.5 | 7.5–8.5 | >9 | Ammonia toxicity increases |
| Dissolved oxygen (mg/L) | >2.0 | 4-10 | <2.0 | Risk of suffocation temperature and free $CO_2$ dependent |
| Water temperature (°C) | >15 | 25–30 | <15<br>>30 | Risk in shallow water in both winter and summer |
| Total Ammonia Nitrogen (TAN) mg/L | 0.8 | 0.5–0.8 | >0.8 | Toxicity is pH, temperature, species and size dependent |
| Alkalinity mg/L<br>EQUIV calcium carbonate ($CaCO_3$) | 50 | 80–300 | <50 | High pH swings, low productivity |
| Hardness mg/L EQUIV $CaCO_3$ | 40 | 100–400 | <40 | Low productivity |
| Carbon dioxide ($CO_2$) (morning) mg/L | 15 | 6–10 | >40 | High $CO_2$ can occur after plankton crash and can be lethal |
| Hydrogen sulphide ($H_2S$) mg/L | 0 | 0 | 0.02 | pH, temperature and DO dependent |
| Nitrite mg/L | 0.1 | 0 | >0.2 | Brown blood disease, suffocation, gill lesions, oedema |
| Phosphorus mg/L<br>as $P_2O_5$ | 0.9 | 0.1–0.5 | ≥1.0 | Excess phytoplankton bloom, especially blue-green algae |

*Source: Boyd 1998.*

**Table 2**. Water quality parameters for nursery ponds.

| Dissolved oxygen (mg/L) | Effect |
|---|---|
| < 0.5 | Small fish can survive brief exposure. |
| 0.5–1.5 | Most species will die at exposure after a few hours or days. |
| 1.5–5 | Most species will survive but can be stressed.<br>Greater susceptibility to disease and slow growth can occur. |
| > 5 | This range is a suitable concentration. |

*Source: Boyd 2001.*

**Table 3**. Common effects of DO concentration on warm-water fish.

## 2.3.4. Solubility of oxygen in the water

There is an equilibrium between oxygen (and other gases) in air and water. At a given constant environment, without oxygen producers and consumers, the equilibrium remains stable. This is called the saturation point. Several factors influence oxygen solubility, but in freshwater fishponds of Bangladesh the most important factor is water temperature, as land elevation is close to sea level (Table 1).

## 2.3.5. Sources of oxygen in pondwater

Oxygen gets into the water under natural conditions in two ways: either through absorption from the air or through photosynthesis, mainly from the small microscopic plants called phytoplankton. Aerators can provide additional oxygen into pondwaters.

## 2.4. Diffusion between air and water

Diffusion from air to water is a slow process, except when the wind is blowing strongly, waves are forming and the water is circulated. The oxygen intake from the atmosphere by diffusion is 1.5 g/m$^2$ per day in small ponds and 4.8 g/m$^2$ per day in big ponds, where the effect of the wind is stronger (Kepenyes et al. 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 actual level of oxygen concentration in the water.

At a low level of DO, diffusion is faster than at a level close to saturation. Farmers should plan to aerate ponds when the oxygen transfer is highest (when DO is low) and avoid using aerators when the rate of transfer is low (near saturation), except for mixing oversaturated upper layers with bottom layers.

In rivers, the main source of oxygen comes from diffusion from the atmosphere, because the plankton density is poor and the flowing/agitating water surface facilitates the absorption of oxygen. Consequently, the DO level in most rivers is at or close to the saturation point of oxygen. This is an important factor for rearing river-spawning fish, particularly silver carp, catla and rohu. Ponds should have high DO to get the best growth, appetite, feed conversion and highest resistance to diseases.

Loss of oxygen by diffusion from water to air occurs in the afternoon. During these hours, the surface layer of pondwater gets oversaturated from photosynthesis, while the deeper layers have low DO levels due to thermal stratification. Other oversaturated gases also escape from water by diffusion. Aeration also reduces dangerous gases in ponds, such as hydrogen sulphide and ammonia.

With this in mind, nursery operators must take the following measures:

- Take the dominant wind direction when constructing a pond to favor the effect of wind on pondwater circulation/aeration.
- Clear pond dikes from high vegetation to allow water circulation/waves generated by the wind.
- Apply an aerator to mix the DO-rich surface water with deeper layers to prevent oxygen diffusion into the air and to create more reserves for night consumption. This can be done quickly in the afternoon.

## 2.5. Oxygen production from 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 produced through fertilization. In ponds that are 1.2–1.8 m deep, phytoplankton produces most of the oxygen. If the pond is shallow or low in plant nutrients because of poor fertilizing, the water can become transparent and the benthic algae will produce most of the oxygen. However, benthic algae does not generate as much zooplankton as phytoplankton does. The harmful filamentous algae also develop well in shallow water. On sunny days, oxygen production is higher, because the rate of photosynthesis is related to the light intensity/quality. This is why it is recommended to clear the dikes of trees.

## 2.6. Factors influencing dissolved oxygen in pondwater

### 2.6.1. Physicochemical factors

The oxygen content in pondwater rarely stays at the saturation point. It is constantly changing, depending on several factors.

Temperature is a particularly strong influence. As the temperature increases, the saturation point decreases. As a result, there is less oxygen in hot water than in cold water (Table 1). However, oxygen consumption by fish almost doubles when the water temperature increases by 10°C (Berka 1986).

### 2.6.2. Biochemical factors

While phytoplankton produces oxygen using sunlight, all living organisms in the pond (insects, fish, bacteria and the phytoplankton) use oxygen at night. Early indicators and risks for low morning DO include the following:

- excess phytoplankton bloom (Secchi disk measurement under 20 cm)
- high stocking rate of fish
- high feeding rate and not all feed consumed
- water temperature above 32°C
- sudden weather changes, such as cloudy weather, temperature drops and rainfall following a long period of sunny days.

## 2.7. Predicting dissolved oxygen concentration at dawn

A simple graphical technique can be used for predicting the DO concentration at dawn from measurements taken at dusk. The DO concentration values measured after sunset and 2 or 3 hours later are used for estimating the linear decline of DO, with respect to time. This technique allows aeration devices to be started early by predicting about 6–7 hours earlier when DO will be lowest in the morning. This is particularly useful during risky days, such as following a plankton crash (Figure 3).

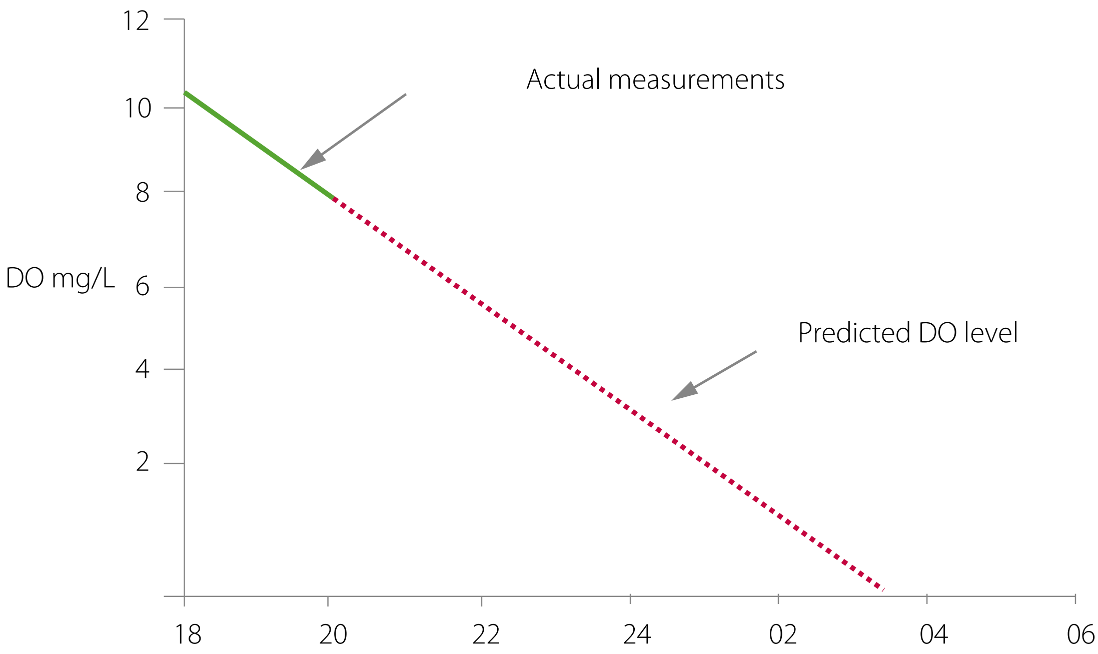
## 2.8. Managing dissolved oxygen levels in nursery ponds

The DO level in ponds fluctuates throughout the day. Daytime DO increases from phytoplankton photosynthesis, with the highest level observed in the afternoon. To maintain appropriate DO levels, it is recommended that farmers follow these guidelines:

- Dry out bottoms between crops and apply lime to enhance organic matter decomposition.
- Avoid excess fish density and overfeeding, as decomposing feces and excess feed consume oxygen. The recommended stocking density for carps in nursery ponds is shown in Table 4.
- Pay special attention to sudden weather changes, such as reduced sunlight, more clouds and strong wind. Prepare pond aerators for emergency use in case of low DO in the morning.
- Lowest DO concentration occurs in ponds in the early morning, and it is frequently associated with high carbon dioxide in the water, which can kill the fish.

| **Stocking** | | **Harvesting** | | **Stocking density** | | **Length of culture (days)** |
|---|---|---|---|---|---|---|
| **Age group** | **Av. Weight (g)** | **Age group** | **Av. Weight (g)** | **Per hectare** | **Per decimal** | |
| Hatchling | 0.0025 | Dhani | 0.1–0.15 | 2,000,000 | 8000 | 10–12 |
| Hatchling | 0.0025 | Fry | 1 | 1,000,000 | 4000 | 30–40 |
| Dhani | 0.1–0.15 | Fingerling | 5 | 200,000 | 800 | 60–70 |
| Fry | 1 | Fingerling | 10–15 | 150,000 | 600 | 75–80 |

**Table 4**. Stocking densities for carp in nursery ponds.




*Source: Boyd et al. 1978.*

**Figure 3**. Predicting DO levels—an example of an extreme case.

- Predicting the DO level in the morning from the previous evening can help farmers prepare for emergency aeration in a timely manner (Figure 3).
- In ponds without aeration, maintain a Secchi disk visibility of 25 cm or greater.
- Use moderate stocking and feeding rates.
- Use good quality supplementary feeds.
- Apply fertilizers in moderate amounts and only when needed to promote plankton bloom.
- Remove submerged and floating aquatic weeds from the pond, except those maintained for dike protection.
- Make sure the vegetation on the dikes allows for sunlight and wind across the surface of the water.
- Maintain a full water level during the culture period.
- Use aeration devices, such as paddlewheels, to maintain appropriate DO levels. Keep them ready for operation all times.

## 2.9. Urgent interventions in case of low dissolved oxygen in nursery ponds

Carps can suffocate if DO is below 1 mg/L. Urgent interventions include the following:

- Start aeration as much as possible.
- Add fresh water. However, water from a borehole is often low in oxygen and contains carbon dioxide. If possible, make sure to aerate borehole water before adding it to the pond.
- If plankton bloom has caused early morning hypoxia, apply 2 mg/L of potassium permanganate. It helps oxidize the suspended dead algae, reducing the use of oxygen by the decomposing algal cells. To reduce free carbon dioxide, apply liquid hydrated lime. Spray it evenly on the water surface at a rate of 50 g/decimal for every 1 m of depth, but do not use lime if pH is above 8.0. Quick lime comes in the form of stones. Carefully spread water on the stones to powder them prior to application. The lime will react with the water to form hydrated lime. The hydrated lime reacts with free carbon dioxide in the water, helping the fish with oxygen absorption.
- Stop feeding until new phytoplankton develop and DO levels normalize.

## 2.10. Ammonia

TAN toxicity depends on the pH and temperature of pondwater. It can be in two different forms (Table 5). Un-ionized ammonia toxicity is about 100 times more toxic to fish than ionized ammonia. Calculate the value of a TAN test to find its toxic un-ionized fraction (Table 5).

Carps can tolerate more TAN than some other species. TAN can be toxic to carps if its concentration is greater than 1 ppm at a pH level of 9.0 or higher. In case of low DO, high levels of ammonia can potentially increase fish deaths.

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 K, Ruso RC, Lund RE and Thursion RV. Thursion. 1975. AqueDUS AMMorita equilibrium catulations d'fect of pH and temperature. Journal of the Fisheries Research Board of Canada 32-2379-2383.*

*Source: SRAC 1997.*

**Table 5**. Percentage of un-ionized toxic ammonia at different temperatures and pH.

Ammonia can often accumulate in pondwater from high fish density, inappropriate feeding and incorrect fertilization. Water temperature and pH influence ammonia toxicity. The following measures are necessary for cases of TAN higher than 1 mg/L:

- Stop feeding and fertilizing with nitrogen and organic materials.
- Reduce fish density, if it is too high.
- Flush the pond or add fresh water to reduce the TAN concentration (though this is often difficult to do in Bangladesh because many ponds cannot be drained).
  - Use aeration to diffuse some ammonia into the atmosphere. This helps oxidize ammonia through aerobic bacteria.
  - Take the following measures to promote phytoplankton and heterotrophic bacteria activity, which will use up ammonia:
    - Use only a phosphorus-based fertilizer.
    - Add an ingredient that is high in carbon in a fast decomposing form, such as molasses, at 50 kg/ha per day to improve the carbon: nitrogen (C/N) ratio, and run aerators to circulate the water and aerate the pond bottom.

## 2.11. Alkalinity and hardness

Measuring hardness and alkalinity is usually done at the beginning of culture. Both can be increased if levels are low, which can happen if the pond is filled with rainwater and the soil pH is low. In cases like this, farmers should take the following steps:

- Fill ponds from a borehole.
- Apply agricultural lime. A minimum of 1000 kg/ha of calcium carbonate is required to provide appropriate alkalinity/hardness (Table 6).

| Alkalinity mg/L | Lime ($CaCO_3$) kg |
|---|---|
| <5 | 3000 |
| 5–10 | 2500 |
| 10–20 | 2000 |
| 20–30 | 1500 |
| 30–50 | 1000 |

*Source: Boyd et al. 2002.*

**Table 6**. Agricultural lime requirements for alkalinity increase.

## 2.12. Carbon dioxide

Carbon dioxide is the base for photosynthesis, so it is especially important in pondwater. Its concentration fluctuates daily. The concentration of carbon dioxide is highest in the morning because of respiration during the night, and it is lowest in the afternoon when it is used by plants and some microorganisms for photosynthesis. If no free carbon dioxide is leftover, it becomes a limiting factor for photosynthesis in the afternoon. In this case, the phytoplankton starts to remove carbon dioxide from bicarbonates. As a result, the pH can reach dangerous levels. Alkalinity reduces excessive pH swings in the water. The higher the alkalinity the lower the rate of change of pH, and the lower the alkalinity the greater the possible change in pH.

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

During low DO conditions after a plankton crash, high concentrations of carbon dioxide can be lethal to fish. These levels prevent the release of metabolic carbon dioxide through the gills and stop the blood from carrying oxygen to fish tissues. The remedy for situations like this is to use potassium permanganate and/or hydrated lime (Section 2.3.3.5).

## 2.13. Nitrite

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

Exchanging or adding fresh water is one remedy for high nitrite concentration. The other is aeration. High DO levels increase nitrite tolerance of carps, and nitrobacter (aerobic nitrification bacteria) need oxygen to transform nitrite into nitrate. Water circulation, using appropriate aerators, also improves DO levels in the pond water at the bottom, which promotes the activity of nitrification bacteria there.

## 2.14. 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 range from 20 to 50 µg/L, and much lower concentrations create stress for fish and make them more susceptible to disease. Hydrogen sulphide is produced under anoxic and acidic conditions by microorganisms. Excess mud on the pond bottom coupled with an anoxic lowest layer of water in the pond promotes the formation of hydrogen sulphide. It can accumulate in undisturbed deep mud on the pond bottom up to 100 mg/L.

There are several ways to control the build-up of hydrogen sulphide:

- Dry and lime the pond soil properly during pond preparation.
- Take particular care during sudden weather changes associated with lowering atmospheric pressure and storms, when hydrogen sulphide can escape from the mud and result in fish deaths. In a crisis situation, treating pondwater with potassium permanganate at 2 mg/L can help by oxidizing hydrogen sulphide.
- Use appropriate feeding methods to avoid accumulating wasted feed on the pond bottom. To free the accumulated gas from the mud, use a *harra* to rake the pond bottom monthly when the DO in the water is high and simultaneous aeration is safe.

## 2.15. Phosphorus

Phosphorus is a limiting factor for the photosynthesis of phytoplankton. The required concentration in pondwater is 0.1–0.5 mg/L as $P_2O_5$. The bottom soil can absorb phosphate ions not absorbed by phytoplankton. That is why it is suggested to use triple super phosphate (TSP) in ponds on most days. Phosphorus that is contained in mud can be released into the pond water following the next pond preparation.

Photo credit: Francois Rajts

Showing the force of a venturi aerator.

# 3. Collecting water samples

Taking water samples should be done at a specific time of day. For example, morning DO is measured when it is at the minimum level, which is generally at sunrise, while the highest level is around 15:00–16:00. Water samples should be taken from below the water surface, because the upper few centimetres of water can overheat or contain reduced/improved quantity of dissolved gases. When taking a DO sample using the Winkler method, collect the water from a depth of approximately 30 cm, while taking a sample simultaneously from the surface.

Emergency water quality testing is required for algal blooms, phytoplankton crashes, a sudden weather change, unusual fish behavior or an outbreak of fish disease. The suggested frequency of water quality testing is summarized in Table 7.

| **Frequent measurement** | | **Occasional measurement** | |
|---|---|---|---|
| **Parameters** | **Frequency/time** | **Parameters** | **Frequency/time** |
| pH | Weekly<br>(6:00 and 15:00) | Alkalinity | After filling the pond |
| DO | Every 3–4 days<br>(6:00 and 15:00) | Hardness | After filling the pond |
| Water temperature | Every 3–4 days<br>(6:00 and 15:00) | $CO_2$ | During a plankton crash<br>(morning) |
| TAN | Weekly<br>(15:00) | $H_2S$ | Foul smells and fish gasping. Not likely in Talbaria (morning) |
| Transparency<br>(Secchi disk) | Weekly<br>(12:00 and 15:00) | Phosphorus as $P_2O_5$ | Poor fertilization result |

**Table 7** Frequency of water quality measurements.

# 4. Pond aeration

The supply of oxygen in ponds is not always sufficient to support the healthy growth and development of fish. Daily changes in DO in pond water can result in fish stress, poor growth and potentially deaths. The solution is to supply oxygen through aerators. For nursery ponds, using a paddlewheel aerator is preferred.

## 4.1. The importance of pond aeration

Pond aeration provides appropriate oxygen levels for cultured fish to meet their normal metabolic demand. In baors, beels, haors and other natural waters, the oxygen supply from phytoplankton, vegetation and diffusion from the atmosphere usually provides more oxygen than fish populations actually need. In aquaculture ponds, the high density of fish, plankton and decomposing wastes require more oxygen per given volume of water area than in natural waterways. In semi-intensive culture systems, it is likely that the amount of oxygen supplied from natural sources will not always satisfy the oxygen demand of pond biota.

Investigations of 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 mrigal (*Cirrhinus mrigala*) and rohu (*Labeo rohita*). Oxygen consumption of Indian major carps, mrigal and rohu, were tested in fresh water at 29°C–31°C under different oxygen concentrations. It was found that both species are oxyconformers, significantly reducing their consummation of oxygen under hypoxic conditions. At the same time, ammonia secretion significantly increases. Oxygen consumption as an index of total energy use and the ammonia quotient, which is the ratio of ammonia excreted to oxygen, consumed as an index of protein metabolism indicates changes in protein metabolism for both species under low DO conditions. The mean values of oxygen consumption and ammonia excretion under normal and hypoxic conditions are given in Table 8.

Fish stressed from frequent low DO will not eat and grow well. It is even possible for one phytoplankton crash to kill a whole batch of fish production.

| Species | Parameters | Normal condition (Mean values ± S.E) | Hypoxic condition (Mean values ± S.E) |
|---|---|---|---|
| Mrigal* | 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[1] | 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 |

**Note**: The temperature was 29°C–31°C and the fish were starved for 24 hours prior the experiment.
**15.4–17.4 cm total length and 33.8–43.6 g average weight.
***15.9–18.9 cm total length and 35.8–47.8 g average weight.

*Source: Extracted from Padmavathy 2002.*

**Table 8**. The mean values for respiratory parameters of mrigal and rohu fingerlings in freshwater.

Aeration supports far higher stocking densities and feeding rates. It also reduces water quality problems and maximizes production and profit from fish culture compared to non-aerated ponds.

## 4.2. Principles of aerating pond water

Under normal conditions, oxygen enters ponds from the air into the water by diffusion (in addition to oxygen produced by photosynthesis) through the air-water interface. However, once the top layer reaches the saturation point, no additional oxygen can enter the water without water circulation. When there is wind blowing across the surface of the pond, the interface area increases from the waves generated by the wind, so more oxygen enters the water. Another effect of wind is that it mixes the top layer of water with the deeper areas, which continues oxygen diffusion into the water for a longer period of time. However, if the water becomes oversaturated through photosynthesis, diffusion can occur in the opposite direction, with oxygen being lost to the air.

Aquaculture pond aerators increase the air-water interface by introducing air into the water and spraying water above the water surface. Both increase the area of the interface, which allows greater oxygen diffusion into the water.

There are two ways of describing aerator performance. The standard oxygen transfer rate (SOTR) is the amount of oxygen added to water in 1 hour under standard conditions. The units of SOTR are pounds of oxygen per hour, which can be multiplied by 0.45 to derive the metric equivalent in kg of oxygen per hour. Standard aeration efficiency (SAE) is the standard oxygen transfer rate divided by the power requirement in horsepower (hp). Units of SAE are pounds of oxygen per hp per hour, which can be multiplied by 0.61 to derive an SAE in metric units of kg of oxygen per kilowatt per hour (Boyd 1998).

## 4.3. Paddlewheel aerators

Paddlewheel aerators are surface aerators that are supported by floats and powered by electricity. Electricity and water can lead to significant health and safety issues. Workers should always turn off electrically driven aerators before entering ponds. While commercially available aerators can be considered expensive, some farmers develop homemade aerators that provide similar results (Figure 6). The oxygen input capacity of a paddlewheel aerator is relatively high, with an SAE around 1 kg of oxygen per kilowatt per hour.

## 4.4. Oxygen budget of the pond ecosystem

Phytoplankton consumes oxygen during the night, while in the daytime oxygen production exceeds consumption. However, whenever there is excess bloom, the sheltering effect of the high density of phytoplankton can kill phytoplankton in sheltered layers, which results in additional oxygen consumption.

The oxygen consumption among zooplankton is constant day and night. Dangerous situations can arise when excess zooplankton eats up all phytoplankton, which can lead to anoxia. In this case, continuous aeration is recommended until the phytoplankton develops. That is why fertilization should be rigorously maintained, according to Secchi disk readings.

The DO demand of pond bottoms varies according to the quantity of decomposing organic wastes (much greater at higher feeding) and the consumption by the benthos. For a pond 1 m deep, the daily oxygen demand of the bottom would be 1–3 mg/L (Kepenyes et al. 1983).


**Figure 6**. Paddlewheel aerators.

Oxygen consumption among carps in a pond under semi-intensive culture is only a fraction of the total oxygen demand of the pond. Benthos, plankton and decaying organic wastes are the main consumers, sometimes resulting in anoxia in the early morning. Mohapatra (2017) found an inverse relation between the development stage and oxygen consumption of Indian major carp fingerlings. Catla was the highest oxygen consumer, followed by rohu and mrigal (Table 9).

Boyd (2018) calculated the oxygen budget for 1 ha of a channel catfish pond (Table 10), another freshwater aquaculture species grown in the US.

## 4.5. The benefits of using aerators in nursery ponds

The benefits of using pond aerators include the following:

- They increase the security for the survival of cultured fish. There is a risk for high mortality from sudden plankton die-off or other sudden environmental changes. To save their fish, farmers must quickly deploy their emergency aerators kept on standby in the farm storage.
- They improve the oxygen budget of ponds by increasing the quantity of oxygen stored in the pondwater through destratification (if afternoon destratification is applied).
- Accelerating the mineralization of organic sediment improves the pond soil.
- Regular aeration for few hours per day ensures optimal habitat for fish, with morning DO levels above 3 mg/L.
- The pond remains well mixed, and the entire pond area is available for fish habitation.
- Aeration systems can increase fish stocking and feeding rates.
- They provide healthy fish, better feed conversion, better growth rate and higher profit for fish culture.
- They increase the natural food in ponds by providing a better environment for zooplankton development.

| 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: Mohapatra et al. 2017.*

**Table 9**. Oxygen consumption of advanced fry, fingerlings and advanced fingerlings of Indian major carps (mg/kg/h).

| Budget component | Oxygen available or required (kg/ha) per 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 |
| Total available oxygen | 110 |
| Total oxygen demand for respiration | 222 |
| Oxygen required from mechanical aeration | 112 |

*Source: Boyd 2018.*

**Table 10**. Typical night-time oxygen budget for a 1 ha catfish pond.

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# Annex 1. An aeration tower

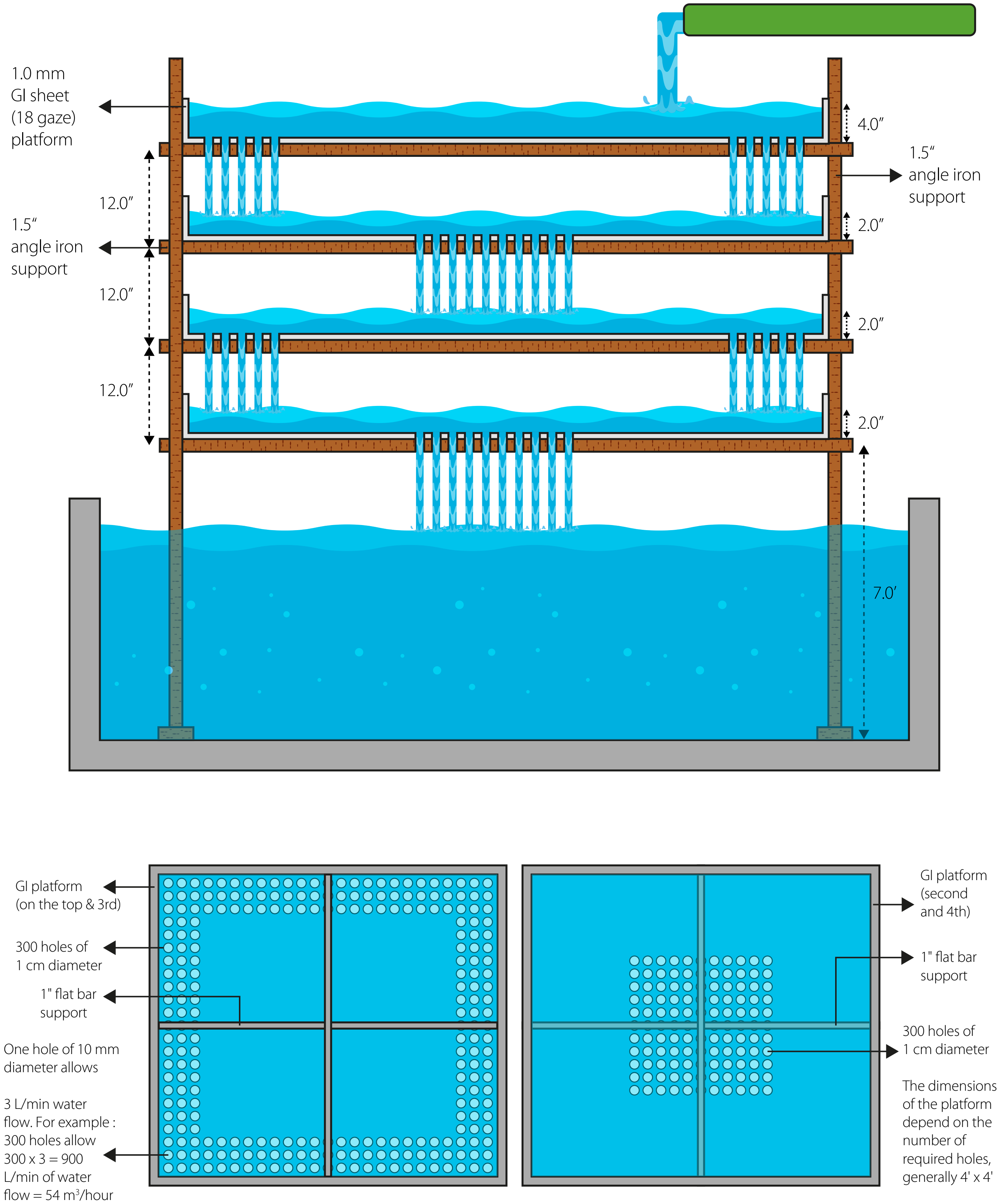


**Figure 4**. Sketch of an aeration tower with a capacity of 50 $m^3$ per hour.

# Annex 2. Net profit comparison

| Total area of 10 ponds: 20,000 m² (500 dec) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **One year operation with IMC & Chinese carp 4000 kg ♀ and 3000 kg ♂ broodstock** | | | | | | | | | | |
| | | **Traditional hatchery** | | | | **Hatchery with aeration tower** | | | | |
| **Item** | **Unit** | **No** | **Kg** | **Unit Price BDT** | **Total BDT** | **Unit** | **No** | **Kg** | **Unit Price BDT** | **Total BDT** |
| **INCOME** | | | | | | | | | | |
| Selling spawn (4000 kg ♀ breeders; x2 time breed; 1 kg spawn produced from 6 kg ♀ two times) | kg | | 1333 | 2500 | 3,332,500 | | | | | |
| Selling spawn (4000 kg ♀ breeders; x2 time breed; 1 kg spawn produced from 5.3 kg ♀ two times) | kg | | | | | | | 1500 | 2500 | 3,750,000 |
| Selling discarded breeders (20%/year) | kg | | 1200 | 200 | 240,000 | | | 1200 | 200 | 240,000 |
| **Total fish sales** | | | | | **3,572,500** | | | | | **3,990,000** |
| **OPERATIONAL COST** | | | | | | | | | | |
| Pond maintenance | (m²) | 20,000 | | 15 | 300,000 | 20,000 | | | 15 | 300,000 |
| Pumping (out, in, maintenance and flushing) | m³ | 60,000 | | 4 | 240,000 | 60,000 | | | 4 | 240,000 |
| Rotenone | kg | | | 20 | 300 | 6000 | | 20 | 300 | 6000 |
| Lime | kg | | | 500 | 20 | 10,000 | | 500 | 20 | 10,000 |
| Urea | kg | | | 120 | 30 | 3600 | | 120 | 30 | 3600 |
| TSP | kg | | | 250 | 30 | 7500 | | 250 | 30 | 7500 |
| Mustard oil cake | kg | | | 700 | 40 | 28,000 | | 700 | 40 | 28,000 |
| Cow dung | kg | | | 4000 | 1 | 4000 | | 4000 | 1 | 4000 |
| Parasite control | ls | | | | | 10,000 | | | | 10,000 |
| Carp broodstock (20% replacement/year, 7000 x 0.2 kg) | kg | | | 1400 | 300 | 420,000 | | 1400 | 300 | 420,000 |
| Fish feed (1.5% BWt/d x 300 days) | kg | | | 31,500 | 40 | 1,260,000 | | 31,500 | 40 | 1,260,000 |
| Feeding and guard | m² | 20,000 | | | 6 | 120,000 | 20,000 | | 6 | 120,000 |
| Netting 10 ponds (selecting, health control) | No | 200 | | | 500 | 100,000 | 200 | | 500 | 100,000 |
| Transport breeders to and from hatchery | ls | | | | | 50,000 | | | | 50,000 |
| GnRH (10 vial; breed two times) | Vial | 100 | | | 350 | 35,000 | 100 | | 350 | 35,000 |
| PG (2.5 mg) | No | 10,000 | | | 5 | 50,000 | 10,000 | | 5 | 50,000 |
| Plastic and jute bags (set 2 plastic + 1 jute) | No | 5300 | | | 20 | 106,000 | 8000 | | 20 | 160,000 |
| Oxygen (refill cylinder) | No | 30 | | | 800 | 24,000 | 30 | | 800 | 24,000 |
| Hatchery staff | ls | | | | | 336,000 | | | | 336,000 |
| Hatchery electricity consumption | KW | 24,000 | | | 7 | 168,000 | 30,000 | | 7 | 210,000 |
| Depreciation aeration tower installation (20 years) | | | | | | | | | | 2000 |
| **Total operational cost + depreciation** | | | | | | **3,278,100** | | | | **3,374,100** |
| **NET INCOME** | | | | | | | | | | |
| **NET INCOME** | | | | | | **294,400** | | | | **615,900** |
| **Profit % of operation cost** | | | | | | **898** | | | | **1825** |

*Source: Rahman, personal communication, 2013.*

**Table 14.** Net profit before and after installing an aeration tower in traditional hatcheries.

## About WorldFish

WorldFish is an international, not-for-profit research organization that works to reduce hunger and poverty by improving aquatic food systems, including fisheries and aquaculture. It collaborates with numerous international, regional and national partners to deliver transformational impacts to millions of people who depend on fish for food, nutrition and income in the developing world. Headquartered in Penang, Malaysia and with regional offices across Africa, Asia and the Pacific. WorldFish is a member of the CGIAR, the world's largest research partnership for a food secure future dedicated to reducing poverty, enhancing food and nutrition security, and improving natural resources.

For more information, please visit www.worldfishcenter.org