Water Quality and Disease Management

FishAdapt Project




Food and Agriculture
Organization of the
United Nations

Cover photographs:

Top left to right: Water quality testing; fish farming. Bottom left to right: farmed pond; water quality tools

Water Quality and Disease Management Manual

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Preparation of this document

In view of the impacts that climate change is going to have in the world and in particular on food security and vulnerability, the Food and Agriculture Organisation of the United Nations has launched a series of initiatives targeting the awareness, the capacity building of both ministerial officers, development agents and communities on the sustainable management of natural resources.

Climate smart aquaculture is fundamental to adapt traditional aquaculture to the future challenges of the sector. Therefore it is important to invest in some key aspect of fish farming that are essential to secure production against risks of losses. Water quality and disease management are two aspects that are critical in production due to the consistent losses that can be suffered due to not appropriate management.

On this regard FAO prepared a comprehensive manual to give information and methodologies to monitor and maintain good water management for key farmed fish, together with strategies to improve biosecurity and tools to identify common fish diseases.

The present manual was prepared by Dr. Edoardo Pantanella aquaculture consultant and climate change specialist, supervised by the FAO FishAdapt Team Leader Mr. Jose Parajua and reviewed by the FAO national aquaculture expert Daw Moe Kyi Phyu and the national climate change adaptation - disaster risk management expert U Aung Tun Oo.

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Abstract

This manual seeks to provide a comprehensive technical knowledge on all the water quality parameters that are essential to be maintained to secure good growth, together with an overall knowledge of the biosecurity strategies and diseases that need to be acknowledged to reduce risks of mortality in aquatic animals.

Different aquaculture systems are described with details about management of aquatic animals and water resources. Some emphasis is also put on the need to adjust optimal water characteristics depending on the species farmed, also with a focus on integrated aquaculture with aquatic or terrestrial plants.

The section is followed by a detailed description of the different water quality parameters, their ranges and the ways they influence the living conditions of the aquatic animals. Parameters are divided into three main groups consisting in physical, chemical and biological parameters. Tools for measuring and methodologies are also provided in order to guide the practitioners towards efficient monitoring.

The successive section gives an overview of the farm operations that need to be followed to optimize production and to improve the biosecurity in farms. Details on how to improve the pond bottoms, liming, correct choices for water intake, and biosecure farm layouts are described with examples from good practices developed in neighbouring countries.

The final part gives a general overview of the common diseases occurring in fish farming, together with the treatment strategies that should be follows. However it is important to underline the need to work closely with the dedicated DOF’s Fish Disease Section in order to build an efficient early monitoring system to efficiently inform farmers about risks and remedies. In addition it is also important to liaise with the veterinary services to confirm diagnosis and design appropriate treatment strategies.

This manual aims to give to governmental and not governmental organizations a basis to improve the knowledge and management of water quality and biosecurity and to provide knowledge in communities on the different farming approaches that need to be followed to increase resilience in the production of aquatic animals.

Contents

Abbreviations/Chemical symbols

C	Carbon
Ca	Calcium
$CaCO_3$	Calcium carbonate
CaO	Lime
$CaSO_4$	Gypsum
Cl	Chloride
CO_3	Carbonate
DO	Dissolved oxygen
CH_4	Methane
Fe	Iron
HCO_3	Bicarbonate
H_2CO_3	Carbonic acid
K	Potassium
Kg	Kilogram
KH	Carbonate hardness
L	Litre
m	Metre
m^2	Square metre
m^3	Cubic metre
mg	Milligram
Mg	Magnesium
N	Nitrogen
Na	Sodium
NaCl	Sodium chloride
NH_3	Ammonia
NO_2	Nitrite
NO_3	Nitrate
P	Phosphorus
pH	Concentration of hydrogen ions (H^+) determining the acidity of the water
PPT	Part per thousands (equivalent to gram/litre)
Si	Silicon
SO_4	Sulphate

Glossary

Autotrophic	an organism capable to produce its own food by using light and inorganic elements.
Broodstock	mature individuals used in aquaculture for breeding purposes
Buffer	an element that resists changes in pH
Buffering capacity	the capacity to resists changes in pH through the consumption of a buffer to contrast the addition of an acid or a base.
Cachexia	weakness and wasting of the body due to severe chronic illness
Carnivorous	animal feeding on other animals
Carrying capacity	the number of living organisms that a pond or water body can support without environmental degradation
Cyanobacteria	a type of bacteria that is capable of photosynthesis
Eutrophic	an environment rich in nutrients that supports a dense plant population
Herbivorous	animal feeding on grasses
Heterotrophic	an organism not able to produce its own food but needs to procure it from other organisms
Macrophyte	an aquatic plant growing in or near water bodies.
Oligotrophic	environment that offers very low levels of nutrients
Phytoplankton	microscopic marine algae
Plankton	the sum of microscopic organisms, such as microalgae or phytoplankton, microscopic animals or zooplankton, present in the water that constitutes the base for the nutrition for planktivorous fish.
Planktivorous	animal feeding on plankton
Primary production	production of organic compounds from carbon dioxide and photosynthesis, by using solar radiation as source of energy,
Siltation	the obstruction caused by sediments made by sand or soil
Sterilization	The process of making something free from pathogen and microorganisms in general
Zooplankton	small or microscopic heterotrophic organisms that drift with water currents

Introduction

In aquaculture all the aspects that improve the farm productivity and growth efficiency should be considered. Genetic selection, nutrition, farm management, biosecurity are all key factors that should go together with water quality, whose parameters are of vital importance for the aquatic species wellbeing, growth and health.

Water quality encompasses a multitude of parameters that can be summarized in physical, chemical and biological ones. Obviously there is not a unique set of optimal water parameters, as they change and are optimized for the needs of the target species and even their growth stages. Water parameters can in fact change sensitively depending on the type of animal, such as fish (carnivorous, planktivorous), crustaceans, molluscs or even aquatic plants.

In the contest of climate change and building resiliency it is important to consider not only the optimal conditions for each farmed species, but also the necessary management that could improve the physical-chemical characteristics of the water, avoids contamination from biological and chemical agents, and reduce the impact of wastes.

The present manual seeks to provide an overall knowledge of the main parameters, optimal ranges for some key farmed species, and the tools for measuring the water. Indications of the management of pond systems are also provided to avoid microbiological contamination from external sources to prevent infections as well as tools to identify the most common diseases.

Water quality in aquaculture

Characteristics of aquaculture environments

Aquaculture can be defined as "*the rearing of aquatic animals or the cultivation of aquatic plants for food, products, energy*". Each species has different needs, which should be met not only by the physical characteristics of the water (temperature, dissolved oxygen, salinity, suspended solids) but also by the different concentrations of minerals. This is particularly true when some elements are key constituents of the trophic chain, such as phytoplankton that directly and indirectly sustains all the animals of the upper food chain. A particular emphasis has to be put also on the aquatic plants that can act as sink of animal wastes and contribute to absorb elements whose high concentrations are harmful for fish.

The above definition particularly matches the description of water quality: "*The physical, chemical or biological factors that affect the optimal functioning of an ecosystem or a particular animal/crop*". This definition explains that specific sets of parameters differ among different productions. One example of this is the eutrophic water (water rich of phytoplankton, zooplankton) that is particularly important for either planktivorous fish, crustaceans or shellfish.

On the other hand intensive aquaculture can lead to the build-up of nutrients/ions that are harmful for aquatic animals (i.e. ammonia, nitrite) but can be ideal for the growth and the quality traits of algae or even terrestrial plants.

Main water quality factors

Several factors (Fig. 1) affect the quality of water and can be concurrent causes of losses in farmed animal if these are not managed properly.

The characteristics of the land for example can be critical for the effects of acidic soils or the increase of turbidity in the water, which eventually reduces the possibility to have good photosynthesis. In addition many nutrients are accumulated in the soil and can be released into the water column to favour growth. On the contrary the accumulation of organic matter at the bottom of the ponds if not properly managed can create anaerobic conditions and favour the production of greenhouse gases such as methane.

Sources of water are also important because not all the waters are similar in terms of chemical or biological characteristics. Surface water could be in fact contaminated by pesticides, or possess high loads of bacteria and other potential pathogens or parasites. On the contrary ground water could be contaminated by heavy metals or be poor in oxygen.

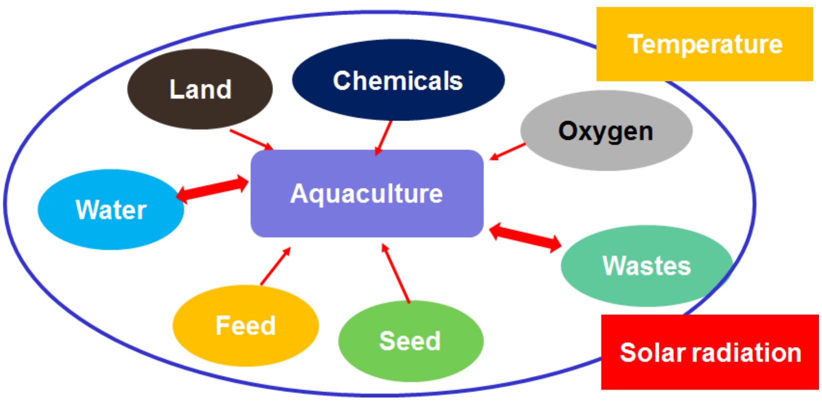


Fig.1 Factors affecting water quality

The characteristics of the feed also determine sensitive changes on the quality of the water, this because high-protein diets are more likely to bring higher quantities of toxic ammonia from the urine of the fish, while diets rich in fibres or quickly dissolving pellets increase the organic load and thus reduce the dissolved oxygen in the water.

Different species of fish, as well as different ages of the same fish should be considered. Some fish, like catfish, pangassius are much resistant to poor water quality, while carnivorous ones are less. Fry are more susceptible to the water chemistry than their grow-out siblings.

Waste management is indeed one of the most important factors of farming animals, loads with feed well beyond the carrying capacity of the ponds or cages bring to anaerobic conditions in the bottom, but also lower dissolved oxygen in the water. Higher stocking densities with fish eating protein-rich diets quickly build-up toxic levels of ammonia, which eventually brings to death the animals, if water is not exchanged or adequately treated.

Oxygen is the essential to keep alive and support the metabolism of all the organisms. There are several thresholds in dissolved oxygen (DO) that need to be considered when farming, as they affect the metabolism of the animals, or the treatment and renovation of the water.

In the water it is important the presence and concentrations of particular ions, as they contribute to the primary production in ponds and water bodies. However excessive concentrations of these can lead to eutrophication, which may be negative for some species. The loads of chemical compounds are also another factor of risk, particularly when water is abstracted in areas close to agricultural runoffs or where farmers spray pesticides and fungicides, or near industrial compounds where it is likely that factories indiscriminately and illegally pour their wastes in the water streams. Likewise, presence of heavy metals can affect the possibility of farm fish due to the risk of accumulation in the body of the animals that are then going to be consumed by people.

Solar radiation on the other hand contributes to provide the necessary energy for phytoplankton, and thus supports the whole food chain. Low radiation, as it occurs in water under intense shadow conditions or overcast sky, is likely to have a depressive effect on the primary production as well as the turbidity, since sun rays cannot penetrate deeper in the water column.

Among physical parameters temperatures play a major role, not only because each farmed species has its optimal ranges, but also because productivity in the water can be slowed down by too high or too low temperatures that affect the primary production and the functional state of micro-organisms that are supposed to digest wastes or process the water.

Nutrients for water productivity

As mentioned before many ions naturally occurring in nature are dissolved in the water, their presence is variable as concentrations depend on the type of soil and ground water. Some elements like sodium (Na), calcium (Ca), potassium, (K) iron (Fe), magnesium (Mg), chloride (Cl), bicarbonate (HCO_3), and sulphate (SO_4) are easily available, have little or variable seasonal variations, and are usually in sufficiently large supply with respect to the organisms' requirements. Other elements such as phosphorus (P), nitrogen (N), carbon (C), and silicon (Si) are scarce, show large seasonal variations, and changes in concentrations. Nevertheless elements scarcely available to fulfil organisms' needs need to be integrated by farmers.

The presence of nutrients determine two different conditions in water bodies:

Clean water, low nutrients - Little productivity (algae, plankton) and not large amount of food to support fish growth. This can be the case of spring water, mountain streams that are not affected by any discharges (Fig.2).

High nutrients water - Favours eutrophic waters, increases primary productivity (green water), supports the whole food chain through the species sequence of planktivorous → herbivorous → carnivorous (Fig.3).

On such differences it also interesting to consider that aquaculture wastewater from intensive farms (Fig. 4), which is considered a bad quality water due to abnormal parameters compatible with fish wellbeing, is instead a good source of water for other organisms like aquatic or terrestrial plants, or can be used to provide nutrients to oligotrophic waters, such as extensive ponds thus contributing to the net increase of primary production.

Fig. 2 fish in pristine waters

Fig. 3 eutrophic water

Fig. 4 wastewater

Main types of aquaculture systems in Myanmar

Ponds systems

Ponds are the most common type of aquaculture system worldwide. The water bodies are managed in certain ways to produce one or different aquatic species. Ponds can support the feed needs of the fish compatibly with their type of management, the degree of intensification to stimulate natural food production, and carrying capacity to process wastes from the aquatic animals. Water in ponds has a long permanence, ideally the complete drainage of the body should occur once a year to sterilize and mineralize the bottom, but in Myanmar this type of maintenance does not often occur due to the very large dimension of the ponds.

The productivity in ponds is supported by the natural food that consists mainly in phytoplankton, zooplankton, insects, crustaceans and aquatic plants. The natural food can be increased if sufficient ions are in the water to support the algal production. This envisages the need to add fertilizers to provide natural food to animals or, in case of higher stocking densities to integrate the natural food with the supply of feeds. Depending on the densities of the aquatic animals and the availability of natural food different managements are seen:

Extensive – ponds are closed bodies with very limited nutrients. The only nutrients available are those supplied by soil, decaying organic matter. Fish stay within the carrying capacity of the ponds. Given the very limited amount of elements the plankton is rare and therefore the production is very low, approximately less than 1 MT/ha a year, equivalent to 400 kg/acre. These types of systems do not need any aeration, therefore are very cheap, providing that farmers have enough land to harvest sufficient volumes of fish to sustain their livelihoods and pay for the production costs.

Trap and hold – is a type of system that relies on primary production of the water, but contrarily to the extensive systems the ponds are open and water is added in/pulled out during tidal events. The exchange of water has the benefit to regularly bring in nutrients from the outer waters that can be much richer due to the presence of mangroves, as in the case of coastal aquaculture. The productivity of such systems is low, not due to the lack of food that is available from mangrove areas, but rather by the low stocking densities that occur by trapping scarce numbers of natural larvae during tidal events' inflows.

Semi intensive – in semi intensive ponds the natural productivity is enhanced by the use of fertilizers meant to increase the concentration of the elements needed by phytoplankton. Depending on the degree of intensification the fertilization is also accompanied by a moderate use of feed given to integrate and boost aquatic animal productions. Like the previous system there is no use of any power to provide aeration and densities of 1-2 kg/m^2 are easily achievable.

Intensive – In intensive systems the stocking densities could be very high, therefore fish cannot get enough food from the pond primary production and needs to rely almost exclusively on supplied feed. Given the large loads of inputs and the metabolism of the fish intensive systems require constant aeration, particularly at night, as well as a degree of water exchange to get rid of toxic accumulations of ammonia.

Fig. 5 extensive pond

Fig. 6 trap and hold system

Fig. 7 semi intensive pond with supplementary feeding

Tank systems

Tanks are mainly used in hatcheries with larvae/fry, although in some cases they host grow-out animals and broodstock. The densities vary depending on the volume of water that is exchanged daily. The type of management could in fact consider a partial daily exchange (e.g. 30% a day) or a continuous flow through to get rid of wastes in case of higher stocking densities (from 30 kg/m^3, depending on the species). In such systems animals depend completely on supplied feed and, depending on the densities, from oxygen/aeration that must be run continuously.

Fig. 8 tank system for grow-out

Fig. 9 tank system for nursery

Cage culture

Cage are floating or fixed systems that are hold to the bottom of shallow water bodies by means of bamboos. The type of net size determines the size/age of the animals contained. The water quality in such systems is mainly dependent on external factors: presence of human activities, agriculture, industries, sewage. Therefore water could either contain discrete quantities of nutrients useful to have some degree of plankton, or be almost oligotrophic. In cages fish necessarily need to consume supplied feed as the primary production of these water bodies is not sufficient to meet the nutrient requirements of the animals. On the contrary there are no main management tasks to perform since the continuous flow of water brings in oxygen and take out wastes. Only three aspects need to be kept into account, the presence of potential chemicals discharged upstream, the quantity of oxygen into the water that should be sufficient to maintain the fish alive, and the dispersal of the wastes that should occur within the carrying capacity of the water body.

Fig. 10 cage culture with fixed net

Fig. 11 cage culture with floating nets

Main parameters in water quality

Three different groups to be monitored and controlled: physical, chemical and biological parameters. Water parameters not only set the conditions for the fish to achieve optimal growth, but also to reduce the stress and the improved susceptibility of animals to catch diseases. As it will be clear in the following paragraphs, temperatures (and their sudden changes during the day), oxygen, pH, salinity, are all factors that could increase the capacity of the pathogen to succeed in its infectious capacity, particularly if the fish weakens its defences due to stress derived by suboptimal handling, unfavourable environmental conditions or malnutrition.

Physical parameters

Temperature

It is one of the most important water quality parameters. Temperature influences the water chemistry and the functions of aquatic organisms, in particular it affects:

- The amount of oxygen that can be dissolved in water - important to maintain good respiration in fish, support their metabolism, support microorganism to process wastes. Higher temperatures bring to lower quantities of dissolved oxygen in the water, thus this would bring stress in animals.
- The rate of photosynthesis by algae and other aquatic plants – the process of photosynthesis is in fact maximum within the optimal temperature ranges of the species cultivated, but it seen to decline in suboptimal temperatures.
- The metabolic rates of organisms – Within the optimal temperatures all the physiological processes of the fish are high, this means that animal grow faster and stronger, with less risks to see diseases.
- The sensitivity of organisms to toxic wastes, parasites and diseases – at higher or lower temperatures animals get in general stressed, eat less, have less oxygen, these factors reduce their resistance against pathogens.
- The timing of reproduction, migration, and aestivation of aquatic organisms – certain species of fish need to alternately pass through a period of lower water temperatures and shorter days to higher temperatures and longer days, this would simulate the shift from winter to summer (and vice versa), which trigs the production of eggs, spawning and fertilization in broodstock
- The toxicity of some elements such as ammonia, which is more in its unionized toxic form at higher temperatures

As said earlier temperatures that do not get closer to the optimal ranges of fish reduce growth, improve stress and decrease the animals' resistance against diseases. Reduced appetite and growth are seen for lower and higher temperatures, in the case of spawning eggs the time to hatch increases consistently if temperatures are below the optimal.

Variation in temperatures also affect the population of phytoplankton accordingly. A shift from one type to the other is therefore expected depending on the season and other water characteristics, such as turbidity.

- 20 - 25˚ C - diatom are predominant
- >30˚ C - suppression of benthic organisms
- 30-35˚ C - green algae dominate
- >35˚ C - cyanobacteria dominate

Attention should be put for high temperatures, particularly because the presence of cyanobacteria is the cause of the intense "taste of mud" of the fish when eaten, which can be avoided by manipulating the temperatures in the water or by purging the harvested fish in clean water for a few days before selling.

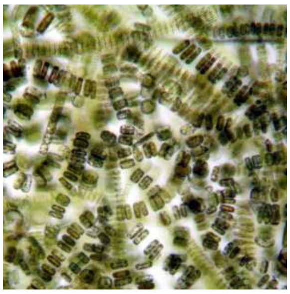


Fig. 12 diatom[1]

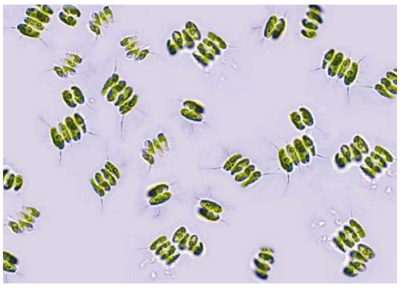


Fig. 13 green algae[2]

Fig. 14 cyanobacteria[3]

One important aspect to remember is that temperatures have higher min/max temperatures in shallow than in deep water. The extreme variability of temperatures is not loved by fish that prefer constant values instead to avoid stress and higher risks of diseases. In deep ponds water still remain cold at the bottom, therefore during hot seasons it would be recommended to keep the water column higher than 4 ft, at least.

Optimal temperature ranges for fish

- 28-32˚C good for tropical major carps and tropical fishes
- <20˚C is sub lethal for growth and survival for tropical fishes
- >35˚C is lethal to maximum number of fish species
- <12˚C is lethal for tropical but good for cold water species;
- 25-30˚C is ideal for shrimp Penaeus monodon culture;

Remedies to cool down temperatures

1. Water exchange, flow is adjusted in base of the cooling needs
2. Planting shady trees or making artificial shades to avoid direct sunlight. Shade can have a minimal effect on phytoplankton if there is no intense reduction of solar radiation.
3. Deeper ponds, to let animals go to the bottom, where water is cooler

Fig. 15 water exchange to cool temperatures

Fig. 16 shading ponds to reduce temperatures

[1] Source: https://diatoms.org/what-are-diatoms
[2] Source: https://www.researchgate.net/figure/Scenedesmus-sp-a-Freshwater-green-microalgae-Scenedesmus-sp-1-b-Scanning-electron_fig1_335924584
[3] Source: https://phys.org/news/2019-10-cyanobacterial-gene-family-photosynthesis.html

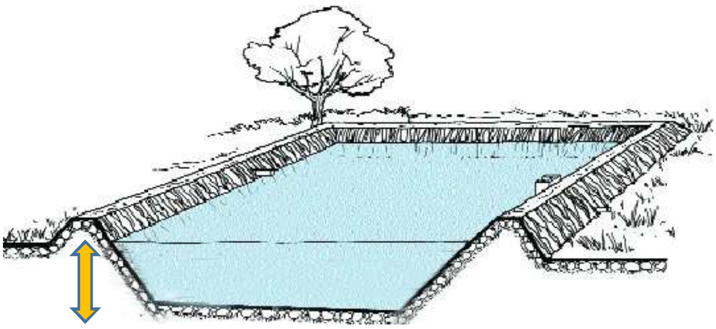


Fig. 17 deeper ponds

pH

It is an indicator of how acid or alkaline the water is. Most of organisms live in a quite narrow and critical pH range. Fish in general thrive best in pH around neutrality: 6-8. Extreme values of pH (<3 or >11) cause damage and death

0 1 2	3 4	5 6	7	8 9	10 11	12 13 14
extremely acid	mildly acid	slightly acid	neutral	slightly alkaline	mildly alkaline	extremely alkaline

Fig. 18 pH levels for aquaculture

pH variability

- pH is affected by the characteristics of the chemicals present in the water ions such as:
    - Acid effect - Sulphate (SO_4), Nitrates (NO_3), carbonic acid (H_2CO_3)
    - Alkaline effect - ammonia (NH_4), bicarbonate (HCO_3)
- Affected by soil acidity. A clayish soil is more likely to pull the water towards acid conditions
- Bacteria activity can increase the acidity of the water (nitrification). Water passes from alkaline conditions due to the presence of ammonia (NH_3) to acid conditions due to the oxidation of ammonia into nitrate (NO_3), which is an acid.

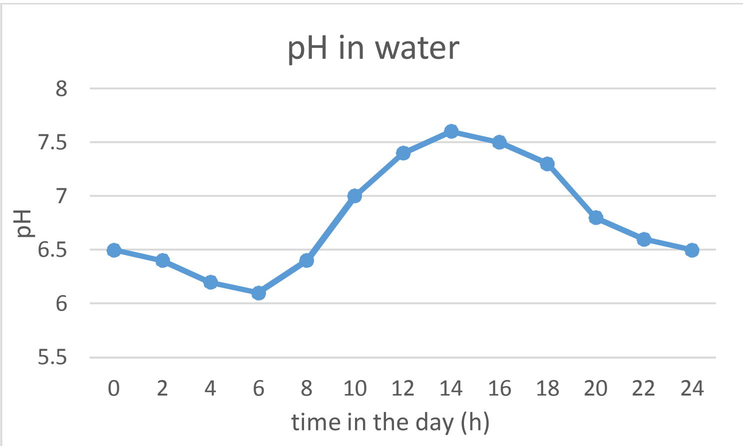


Fig. 19 Variations of pH during the day due to carbon dioxide and photosynthesis in the water

- Variation of pH is also observed in the same ponds between day and night. As written above carbonic acid, which is formed by the carbon dioxide that solubilizes into the water, pulls the water towards acid conditions, however this is more likely to occur during the night, since microalgae and all ponds organisms consume oxygen and release carbon dioxide that becomes carbonic acid. On the contrary during the day microalgae consume carbon dioxide to make their photosynthesis, thus pulling the pH towards alkaline conditions. These variations also suggest the need to measure the pH in two different times during the day: before dawn to check the lower limit, early afternoon to check the upper limit.

Effects of pH

The change in pH towards mild-extreme ranges affects the solubility of the elements particularly for vegetable organisms, which find it more difficult to source adequate amounts of available nutrients. In the case of heavy metals levels of pH below 6 raise their solubility, which increases the risk of toxicity due to accumulation in the body of the fish that are eventually consumed by the people.

Another effect of pH is the conversion of ammonia from its no-toxic ionized form (ammonium ion - NH_4^+) into its toxic unionized form (NH_3). This would have an important impact on the production since keeping the water pH towards slightly acid conditions could help to handle peaks of ammonia that are more likely to remain in its not toxic form.

Remedies to correct the pH

Keep the pH around the neutrality. If the pH drops below 7 gradually add some lime (CaO), gypsum ($CaSO_4$) or calcium carbonate ($CaCO_3$) in batches and keep adding until pH adjusts to the desired level. If pH goes too much above 8-9 adding some fertilizers can help to correct the pH towards the acid range.

Dissolved oxygen

Dissolved oxygen (DO) is essential for aquatic life. A low DO (less than 2mg/l) would indicate poor water quality and thus would make it difficult to sustain many sensitive aquatic animals.

If there is not enough oxygen in the water the following effects can happen:

- Death of adults and juveniles
- Reduction in growth
- Failure of eggs/larvae to survive
- Change of species present in a given waterbody

Tropical fish have more tolerance to low DO than temperate ones. The ideal range to support good growth is to have a concentration in the water of about 7 mg/L. Below that level the tolerance depends on the species. DO of 5 is tolerated by carps, tilapia, perch, catfish and pangassius. However below 3 mg/L the growth rate of these species starts to decreases and stress starts to increase.

0	1	2	3	4	5	6	7	8	9
too low for most fish species		stressful		range of tolerance		support spawning	support growth	support rich productions	

Fig. 20 Dissolved oxygen levels (mg/L) for aquaculture

In ponds that are fertilized and present a good presence of microalgae (green water) the levels of DO during the day are much higher than 8 due to the production of oxygen by algae. However algae during the nights become net consumers of oxygen and compete with fish. This may cause problems if the stocking densities are increasingly higher (above 2 kg/m^2) or the water is too green (too much algae). Such this be the case, problems are observed especially in late night or before dawn, when the DO is at its minimum.

Causes of low Dissolved Oxygen

- High density of fish – too many for the capacity of the pond or water body to recharge the water with oxygen from the air
- Too many wastes in the water – accumulation of organic matter in the water due to excessive feeding, excessive excreta, or use of animal manure to fertilize the pond instead of chemical fertilizers increases the demand of oxygen of the pond. Bacteria present in the water would aggressively compete with fish to source oxygen that they use to degrade the wastes.
- Higher temperatures in water greatly decrease the solubility of oxygen (Fig. 21). The saturation of oxygen in water at 10˚C is 11.5 mg/L, at 21˚C is 9 mg L, at 32 ˚C is 7.5 mg/L.
- Higher salinity of water depresses the solubility of oxygen in a considerable way. The loss can be in the order of 20% between freshwater and seawater (Fig. 21)
- Poor aeration can be one of the causes especially if the fish are outnumbered
- High phytoplankton, with microalgae competing with fish to get oxygen at night. The problems will occur particularly at the early hours of the day before the dawn.
- The use of groundwater as source of water needs careful check as it is most of the time poor in oxygen, which creates immediate problems on fish survival. Intense aeration is needed before pouring the water into the fish tanks.

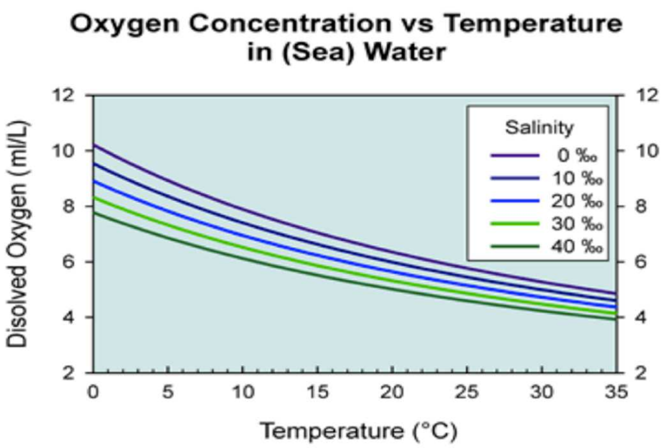


Fig. 21 Oxygen solubility at different levels of salinity and temperatures. The higher the salinity the less the oxygen (20% difference between freshwater and seawater), the higher the temperature the less the oxygen (source: Michael Arthur, Penn State)[4]

Remedies to improve dissolved oxygen in the water

- Reduce the density of fish especially if farmers do not have any paddlewheels
- Decrease the fertilization of the pond to achieve acceptable levels of phytoplankton
- Control the overfeeding to avoid unnecessary wastes
- Avoid to fertilize with organic matter-rich products such as composted vegetables and fresh cow/pig manure. Use of chicken manure is suggested or, better, the use of urea.

[4] Source link: https://serc.carleton.edu/integrate/teaching_materials/water_science_society/student_materials/649

Salinity

Salinity is a measure of the amount of salts in the water. Because dissolved ions increase salinity as well as conductivity, the two measures are related.

Positive ions	**Negative ions**
Sodium (Na)	Chloride (Cl)
Potassium (K)	Sulphate (SO_4)
Calcium (Ca)	Bicarbonate (HCO_3)
Magnesium (Mg)	Carbonate (CO_3)
Ammonia (NH_3)	Nitrate (NO_3)
	Phosphate (P)

The salt in sea water is primarily made of sodium chloride (NaCl).

In other saline waters (e.g. inland waters) the high salinity is due to a combination of dissolved ions including sodium, chloride, carbonate and sulphate.

Aquatic animals grow within optimal salinity ranges

- desirable range up to 2 ppt for common carp and most freshwater fish
- up to 10 ppt no decreases in growth rate of tilapia
- 10-20 ppt for *P. monodon* shrimp;
- 10-25 ppt for euryhaline species
- 25-28 ppt for *P. indicus* shrimp
- 10 ppt suitable for mullet *Mugil cephalus*

Salinity levels that are not ideal for the farmed animals bring stress, diseases and eventually death.

Management is particular critical in coastal areas and along the delta, where seasonality occurs. Freshwater/brackish water conditions are in fact seen during the rainy season and brackish water/seawater conditions are seen during the dry season instead.

Remedies to improve/control the salinity in the water

For saltwater species

- Water exchange during high tides to maintain higher salinity
- Aeration or water movement may be required to equalise the water salinity all over the water column
- Choose a location in areas less affected by freshwater in rainy season.

For freshwater species

- Storage of rainwater in reservoirs during the monsoon and draining up some of the ponds to refill the remaining ones. The emptying of the ponds is also a recommended procedure to do pond maintenance (dry the bottom, liming, sterilize from pathogens), which would improve the productivity and the health status of the animals successively farmed.

Turbidity

It is a measure of the amount of suspended particles in the water. Algae, suspended sediments, and organic matter can in fact reduce the transparency of the water. In Myanmar water turbidity is particularly high during the rainy season, when erosion from the rain puts in suspension clays particles.

Suspended particles diffuse sunlight and absorb heat. This can increase temperature and reduce light available for algal photosynthesis. As a consequence fewer photosynthetic organisms are available to serve as food sources for many invertebrates, this eventually depresses the whole food chain. One drawback that is associated with this condition is that not only the normal phytoplankton is impeded to growth due to scarce light transmission in the water, but also cyanobacteria (blue-green algae) are favoured in this situation because they possess flotation mechanisms that put them in the surface of the water. As mentioned before cyanobacteria are responsible for those muddy off-flavours in the fish, which reduce their quality and their value.

Some of the consequences of murky water is the decline of the invertebrates (crustaceans, other zooplankton) caused by chocking of the filter feeding apparatus. This eventually affects the fish populations that feed on them. In case of high suspended solids there are also direct damages on the fish caused by the clogging or damaging of the gills. Two are the main consequences:

- For aquaculture - pond primary production is reduced and therefore the productivity of the fish is affected, lower growth rates, lower sizes, longer farming periods
- For fisheries – reduced growth of wild fish, and impact on the whole food chain.

The clay turbidity in water to 30 cm or less may prevent development of plankton blooms. At 30 to 60 cm there is generally an adequate condition for good fish production. Values above 60 cm increase the dissolved oxygen, as light penetrates to greater depths, thus encouraging underwater macrophytes.

Secchi disk transparency measurements help to indicate water turbidity for optimum productivity of the pond and good fish culture

Remedies to reduce turbidity

- Addition of more water or lime (CaO) at a rate of 20 mg/L and gypsum on the entire pond water at rate of 200 Kg/ 1000m^3 of pond can reduce turbidity.
- Use a sedimentation pond at inlet when abducting external water to let the solid settle first. This would also prevent siltation (accumulation of sediments on the bottom of the pond and consequent shallowing during the years)

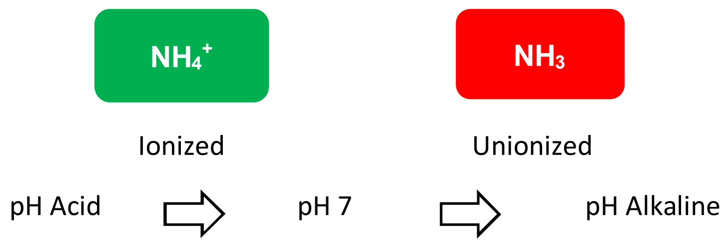
Chemical parameters

Ammonia

Ammonia is the product of aquatic animal catabolism (degradation of proteins from the diet) and are expelled by fish from urine and from the gills. Ammonia is extremely toxic to fish. Any level of ammonia contributes to fish stress and adverse health effects.

However its toxicity depends also on the characteristics of the water, namely pH and temperature. Higher pH (above 7) and higher water temperature make ammonia more lethal since it is in its toxic unionized form (NH_3).

Chemically, ammonia can in fact exist in two forms in water, ionized and unionized. When water is alkaline (pH > 7) ammonia starts to be progressively in its unionized state, which is the toxic form.



Maximum limit of ammonia concentration for aquatic organisms is 0.1 mg/L

Desirable range as total NH_3 0-2 mg/L and Un-ionized NH_3 0 mg/L.

Symptoms of ammonia poisoning

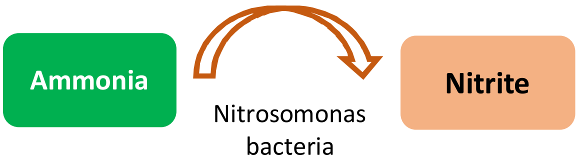
Symptoms: abnormal swimming, leaning right and left, tend to swim vertically. Loss of equilibrium like a drunk person. Fish not feeding, darker gills, larger gills, redness around eyes and fins.

Remedies to high ammonia

- Increase pond aeration
- Immediate stop feeding/fertilization
- Water change out
- Reduction of stock if the pond is overstocked or start regular water exchange
- Addition of liming agents such as hydrated lime or quick lime decreases ammonia and this technique is effective only in ponds with low alkalinity

Nitrite

It is the first product of the oxidation of the ammonia by specific bacteria that oxidise ammonia into nitrate.



Like ammonia it is extremely toxic to fish, and its harmful levels are above levels of 1 mg/litre

Contrarily to ammonia its toxicity is not affected by the pH, therefore it is not possible to adjust the pH to acid conditions in order to reduce the toxicity effect.

The ideal and normal measurement of nitrite is zero in any aquatic system. 0.02-1.0 mg/L is lethal to many fish species, >1.0 mg/L is lethal for many warm water fishes and <0.02 mg/L is acceptable.

Chloride (in the form of salt) is required at a minimum concentration of 60 mg/L

A ratio of chloride to nitrite of 10:1 reduces nitrite poisoning. In general good concentrations of chloride are at about 60 mg/L.

Symptoms of nitrite poisoning

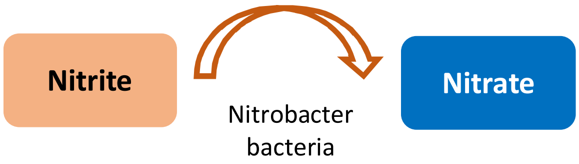
Difficulty in breathing, darker gills, brownish blood (chocolate blood), abnormal swimming, similar to ammonia poisoning, gathering near the water surface, lethargy, redness around eyes and fins.

Remedies to high nitrites

- Reduction of stocking densities
- Increase aeration to maximum
- Stop feeding
- Avoid stress
- Addition of small amounts of chloride salts (sodium chloride, potassium chloride)
- Water change out in emergency or regular water out if stocking densities are excessive.

Nitrate

It is the final product of the oxidation of the ammonia and nitrite



Nitrate is not toxic to fish up to levels of 200-300 mg/l, but the limit is specie-specific. In general levels as high as 10-20 mg/L rarely occur in pond systems. In ponds managed in semi-intensive way having high levels of nitrogen may be more symptoms of over fertilization rather than excreta from fish. Higher concentrations are only achieved in closed recirculating systems whose technology is not in use in Myanmar.

Nitrate is the form of nitrogen is the fastest to be assimilated by the plants. Excessive nitrate, although not toxic for fish, promote too intense phytoplankton bloom that could be dangerous, as it may clog into the fish.

Remedies for high nitrate levels

- Reduction of stocking densities,
- Stop feeding
- regular water change out – irrigation of plants in integrated systems

Phosphorus

Phosphorus allows plants to assimilate more nitrogen. Thus, if sufficient phosphorus is available, high concentrations of nitrates will lead to cyanobacteria, phytoplankton (algae) and macrophyte (aquatic plant) productions.

Phosphorus is monitored because it can be limiting, thus needs to be added in ponds through fertilization. Phosphorus can be present in different forms (eg organic phosphorus, phosphate).

Concentrations of 0.05-0.07 mg/L are optimum and productive; 1.0 mg/L is good for plankton / shrimp production.

Remedies for low phosphorus levels

Add fertilizers with phosphorus

Alkalinity

Carbonate hardness, also known as alkalinity, it is a measure of the buffering capacity of water, which means the capacity of the water to contrast sudden changes/spikes of pH that are stressful for fish. Therefore KH acts as a buffer (or a resistance) to the lowering of pH.

Carbonate hardness (KH) is the total amount of carbonates ($CO3^{=}$) and bicarbonates HCO_3^-) dissolved in water. It is also measured in milligrams of $CaCO_3$ per litre.

In general, water is considered to have high KH at levels of 121–180 mg/litre. Water sourced from limestone bedrock wells/aquifers will normally have a high carbonate hardness of about 150–180 mg/litre. Addition of calcium carbonate enhances the alkalinity.

Waters with total alkalinity of 20 to 150 mg/L contain suitable quantities of carbon dioxide to permit plankton production for fish culture. Alkalinity between 75 to 200 mg/L, but not less than 20 mg/L is ideal in an aquaculture pond. To sum up, alkalinity concentration of:

- <20 mg/L indicates poor status of waterbody
- 20-50 mg/L shows low to medium
- 80-200 mg/L is desirable for fish/prawn
- >300 mg/L is undesirable due to non- availability of CO_2

Remedies for low alkalinity

Add calcium carbonate, oyster shells, limestone, or even egg shells powder depending upon soil pH and buffering capacity

Hardness

General hardness is essentially the amount of calcium (Ca^{++}), magnesium (Mg^{++}) and, to a lesser extent, iron (Fe^{+}) ions present in water.

High hardness concentrations are found in water sources such as limestone-based aquifers and/or river beds, as limestone is essentially composed of calcium carbonate ($CaCO_3$).

Both Ca^{++} and Mg^{++} ions are essential nutrients that and are taken up by plants and animals. Rainwater has low water hardness because these ions are not found in the atmosphere. Hard water can be a useful source of nutrients for plants with no dangerous effects on fish.

Hardness is the measure of calcium and magnesium that are essential to fish for metabolic reactions such as bone and scale formation.

The desirable range is 50-150 mg/L as $CaCO_3$. Values less than 20 mg/L causes stress, 75-150 mg/L is optimum for fish culture and >300 mg/L is lethal to fish life as it increases pH, resulting in non-availability of nutrients.

Remedies for hardness

- Add quicklime to increase the hardness
- Add zeolite to reduce hardness

Calcium

Recommended range for free calcium in culture waters is 25 to 100 mg/L (63 to 250 mg/L $CaCO_3$ hardness)

Water with free calcium concentrations as low as 10 mg/L if pH is above 6.5 can be tolerated by Rainbow trout, 40 to 100 mg/L range (100 to 250 mg/L as CaCO3 hardness) are desirable for striped bass, red drum or crawfish

Remedies for low calcium

- Add calcium carbonate

Heavy metals

Heavy metals can be present if the aquifers are contaminated or if the groundwater has some particular kinds of soils. In case of surface water flooding events can have a dilution effect and is expected to reduce the impact of heavy metals.

Where acid sulphate soils are present, metals can be released as the sediments acidify and the pH is lowered.

Chemical contaminants

There are of various types, most of them are from the agricultural sector. Therefore abstraction of water from common canals when runoff occurs is very risky if water is not stored for reasonable periods in order to get rid of the chemicals.

- Chlorinated
- Glyphosphate
- Paraquat
- Methamidaphos

There are common tests for the level of agrochemical pollution. However these are expensive and may not be worth done by a single farmer.

Names of zooplanktons	Indications	References
Rotifers	Trophic status	Walsh (1978)
Keratellatropica, Hexarthramira	High turbidity due to suspended sediments	Thakur et al. (2013)
Brachionuscalyciflorus	Eutrophic conditions and organic pollution of lakes	Jain et al. (2010)
Cladocerans group (unspecified)	Low concentration of contaminants	Hosmani (2014)
Trichotriatetratis	Pollution caused by accumulation of phosphorous and heavy metal ions	Aslam et al. (2012)
Thermocyclops, argyrodiaptomus	Eutrophic conditions	(Markert et al. 2003)
B.angularis, Rotatoria	Eutrophic conditions	(Markert et al. 2003)
Leeches	Indicates contamination because of presence of PCB (polychlorinated biphenyl) in a river	Uttah et al. (2008)
Leeches	Sensor-bioindicator of river contamination of PCB's	Uttah et al. (2008)
Oyster (Crassostreagi-gas), crabs (Geoticadepressa)	Presence of lead	Uttah et al. (2008)
B. dolabrotus	High turbidity due to suspended sediments	Grizzle (1984)
Copepods (Cyclops & phyllodiaptomus)	Health of the marine body	Aslam et al. (2012)
Cladocerans (moina, daphnia, bosmina)	Health of the marine body	Aslam et al. (2012)

Fig. 22 bio indicators for monitoring of water[5]

Fig. 23 Daphnia (source: Researchgate)[6]

Simpler methods to assess toxicity in non-specific way can involve use of planktonic organisms that are much more sensitive and can be used as bio-indicator for the safe use of water or not. Specific protocols can be developed with the water quality team of the DoF.

Biological parameters

Microorganisms

Microbiological test is to detect the level of pollutions caused by human settlements (sewage). These tests are based on coliform bacteria as the indicator organism. However there are many other different tests to identify the presence of pathogens (*Vibrio, Streptococcus*, etc). Current technology allows the testing of specific bacteria with ready-to-use kits for costs as low as 2-3 USD.

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[5] Trishala K. Parmar, Deepak Rawtani & Y. K. Agrawal (2016) Bioindicators: the natural indicator of environmental pollution, Frontiers in Life Science, 9:2, 110-118. https://www.tandfonline.com/doi/full/10.1080/21553769.2016.1162753

[6] https://www.researchgate.net/publication/319873027_TITLE_1_Resurrection_of_Dormant_Daphnia_Magna_Protocol_and_Applications

The methodology used for these test kits is quite simple as only 1 ml of water needs to be put on the dish.

In case of water heavily loaded with bacteria a 1:10 or 1:100 dilution should be used. A quick procedure for a 1:10 dilution is as follows:

1. dissolve 9 g of sodium chloride in 1 litre of distilled water
2. put 9 ml of the solution in a vial that should be sterilized in autoclave
3. Add 1 ml of the sample in the sterilized vial by paying attention to not contaminate the interior, seal immediately the vial with its cap
4. shake the vial vigorously for at least one minute
5. let the vial settle and the syringe 1 ml of liquid
6. inoculate the petri dish by paying attention to not contaminate the interior, seal immediately the vial with its cap
7. keep in a thermal chamber in darkness for the time and temperature indicated by the producer.
8. Count the colonies from the bottom of the petri dish and mark the counted ones with a permanent marker to avoid recounting the same colony.

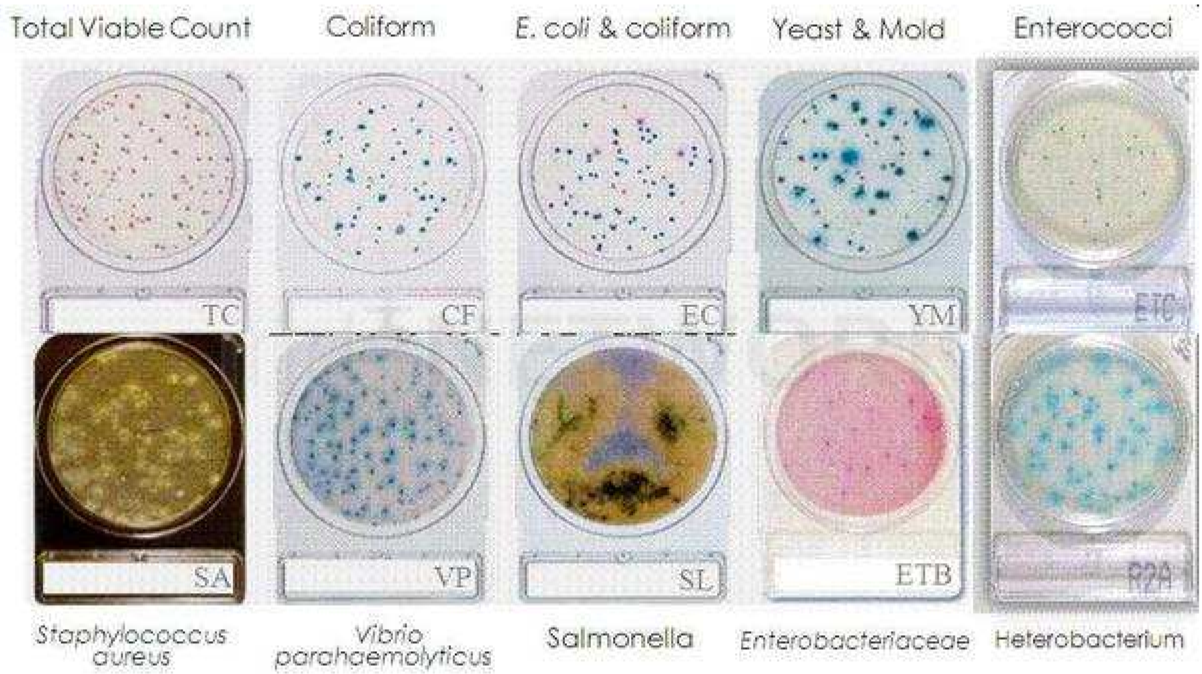

Fig. 24 Petri dishes – ready to use test dishes for different bacteria/yeasts (source: bsmartsci.com) [7]

Measuring instruments

Farmers need a small set of testing instruments for their regular monitoring. More complex analysis for specific monitoring should be easily done in dedicated laboratories due to the cost of purchase of the equipment.

The base equipment should consist in

- pH test kit/meter

[7] https://www.bsmartsci.com/16132477/compact-dry-nissui

- refractometer
- DO meter (alternatively use empiric methods)
- Test kits for analysis of chemicals (ammonia, nitrite, nitrate, phosphorus, alkalinity, hardness)
- Secchi disk
- Thermometer

pH measurement

There are three types of methods to measure the pH in the water. Measurements must be carried in early morning when the acidity of the water is at the maximum for the overnight release of CO_2 by algae.

pH test drop kit - this is a test kit consisting in a liquid reagent. Few drops are poured in a small volume of water (10 ml) and the resulting colour is compared against a reference table. The pH test kit, is cheap, easy to handle, but not very precise as it measures in 1 units of pH. One bottle containing reagent for hundreds of tests cost about 10,000 – 15,000 MMks.

pH paper strip kit - Cheap, easy to handle. It could be used also to determine the pH of soil. Readings are in the range of 1 unit of pH (not very precise). To use simply dip the paper strip in the water to be tested and compare the colour against the given reference. One package for 100 test strips costs about 500-1000 MMKs

pH meter – they are portable and not expensive, (price from 30-40 USD) good from small to large scale farmers. The probe needs to be calibrated with buffer solutions before first use and then regularly to maintain accuracy. Proper rinsing of the probe after use is needed. To use simply turn on the meter, shake into the water for approx. 1 minute until the readings will stabilize. It is very precise as it can measure 0.1-0.01 units of pH. Lifespan is 1-2 years.

Fig. 25 Liquid tester for pH

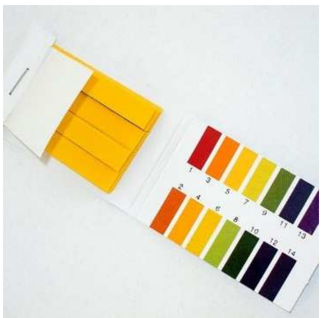

Fig. 26 test strips for pH

Fig. 27 pH meter

Refractometer

It is an optical instrument to read the concentrations of salts in the water. It does not use any batteries and if well maintained can last for years. It simple works by putting a drop of water to be tested on the screen, close the lid and read the value

Once read simply rinse the screen with few drops of freshwater and dry with a soft cloth or tissue paper. The cost of this meter is about 50,000 MMKs

Fig 28 Refractometer

DO meter

Like the pH there are cheap portable meters that are either supplied with a 2-10m long cable for measurements in depths or handheld ones. The cost is however higher than the pH meter. A handheld could cost from 200,000 MMKs. A cheaper alternative is to use test kit drops that cost much less, although they hold enough reagent for only 50 tests. For both methods measures must be done early in the morning, ideally before sunrise.

A practical way to determine if there is enough oxygen in the pond water is to monitor the behaviour of the fish before dawn, when the concentration of DO is allegedly at its lowest level due to the overnight consumption of oxygen by microalgae. The fish in the absence of sufficient oxygen start gasping, they behave like if it “kisses” the surface water. This movement helps the fish the ingurgitation of water and air.

Fig. 29 a DO meter

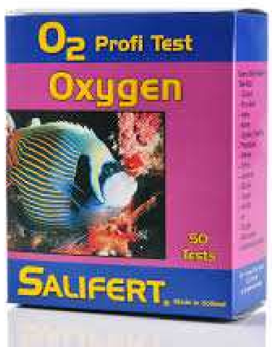

Fig. 30 DO test kit

Fig. 31 Fish gasping at the water surface

Test kits for analysis of chemicals

There is a large variety of kits for almost any measurement needed in aquaculture, or even more. The use is pretty simple as 1-3 vials containing reagents need to be mixed into a 10 ml water sample, and the resulting colour should be compared against a reference table.

Secchi disk

It is a very simple tool to measure the quantity of plankton in the water. It simply works by immerging a disk painted with white and black sectors. The presence of turbidity eventually makes the white and black parts undistinguishable at a certain depth, which will be the measure that is needed. Depending on the depth of the measurement farmers realize if they do need to fertilize the ponds or wait for some more time.

Fig. 32 Test kits to measure different water elements

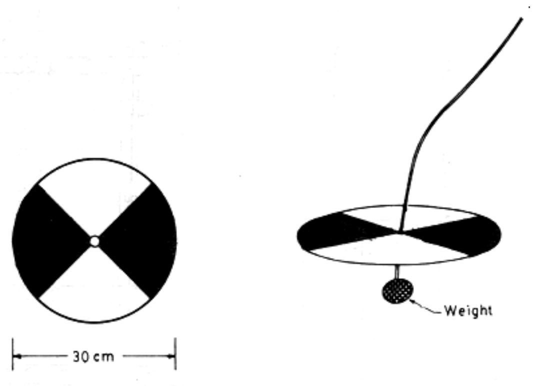

Fig. 33 Secchi disk

Thermometer

Simple tool and cheap to buy. Measurements should be done either in early morning or mid-afternoon to determine the temperatures of the different depths of the ponds. The temperatures can give an indication on the expected levels of oxygen dissolved in the water or the presence of ionized ammonia in the water.

Water management and biosecurity in aquaculture

Improve farming resiliency is the result of many strategies that need to be put in practice to guarantee that the farmed animals do not enter in contact with harmful substances or infectious agents. Moreover good practices need to be followed to minimize the deterioration of the water and the ponds. The following section summarize some of the key management actions that need to be followed to improve farm productivity and minimize the risks.

Water source

For every systems the quality of the incoming water is very important as many chemical and biological hazards can create problems to the aquatic species that are farmed:

- chemical contaminants
- nutrients
- turbidity
- heavy metals
- salts
- oxygen concentration
- temperature
- predators
- parasites
- micro organisms

Different sources of water could be used for aquaculture. Although in most of the farms water sources could not be easily chosen due to scarcity or resources, it is important to build awareness of the potential risks that each water source may put to the farmed animals if precautionary approaches are not taken. This section explains some of the advantages and disadvantages of each choice and provide tools to minimize potential risks.

Ground water

Wells are very common source of water in both cities and rural areas for civil and industrial uses, irrigation. Being in the ground the water may be rich in some dissolved gases that need to be removed (carbon dioxide, hydrogen sulphide). Also the water may be very poor in oxygen.

Advantages	**Disadvantages**
High in minerals	Hydrogen sulphide
Constant availability	Salt inclusion (sea proximity)
Good supply throughout the year	Industrial contamination
No parasites	Possible heavy metals contamination
	Bacteria contamination from sewage
	Low dissolved oxygen

Rain water

Rain water can be collected in any place. If collected from roofs it is a good practice to avoid the first water to get rid of possible dirt or parasite cysts carried by birds' droppings (*).

Advantages	**Disadvantages**
Free	Seasonal
Clean	Unpredictable
No pathogens/parasites*	Needs a storage tank
No salinity	No minerals

Surface water

Water flowing on the ground, such as rivers ponds, canals is an easy source of water, although there may be some seasonality on the availability of good quality water.

Advantages	**Disadvantages**
Easy supply	Risk for pathogens and parasites
Fairly cheap	Attention to chemical contaminants
	Salinity

Water intake

It occurs especially with surface water. Farmers need to be sure of pumping in water away from pesticide treatments in neighbour crops. There is also the need to take into account the possible presence of turbidity from water rich of suspended solids. In this case it is necessary to pass the water through a sedimentation ponds where solids can settle before being stored into the reservoir.

This water treatment helps to avoid siltation in ponds, a phenomena also present in trap and hold systems where pond start to become shallower and shallower, thus improving the risks of inefficient water exchange and increases of water temperatures in the ponds, which would eventually increase the risks of diseases.

Fig. 34 Sedimentation pond to settle sediments. Turbid water is left settle for a certain period of time to let the clay settle.

Filtration of the water

It is an important procedure that would avoid problems to newly stocked ponds, reservoirs or already stocked ponds that need some water refill. The position of a fine net mesh would avoid the invasion of unwanted species (predating fish, larvae, eggs, frogs, etc) that can successively harm the farmed animals.

A more efficient filtration is the sand filter that can be contained in either a tank or a small impoundment. Sand beds are very useful to control parasites, enteric viruses, bacteria, protozoa and microorganisms in general with a removal capacity of x100 - x10,000. For heavy metals the efficiency is 99% and some chemicals (pesticides) can also be controlled to some extent. The sand bed should be composed by at least 12 inches of fine sand (0.15-0.35 mm size) supported by a gravel layer to let the water leave the tank without eroding the sand layer.

The sand bed should run continuously to let the most superficial layer in contact with the water to form a tiny layer of microorganisms (called the Schmutzdecke). This bacterial filter is the core part of the sand filter as these microorganisms are those involved in the real filtration process. This layer ripe in 1-2 days to reach its best efficiency. The filtration speed is about 100-200 litres/hour per every m^2 of bed.

Fig. 35 pond inlet with screen filter

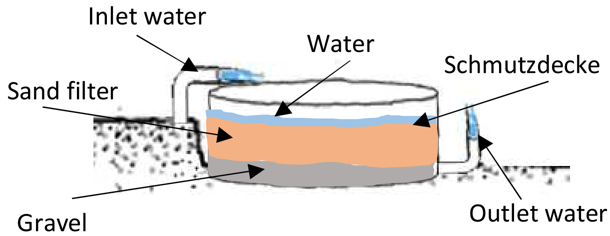

Fig. 36 Sand filter

Farm layout to improve biosecurity

The farms should be designed as a closed systems, where water is continuously recirculating from the reservoir, pond, treatment canals and back to the reservoir. Such design avoids any need to supply water from outside when conditions for water abstractions are not favourable (e.g. salinity at the end of the dry season, chemical contamination from agriculture, etc.) thus letting the farmer to decide the best period to refill his/her reservoir. Keeping the system closed helps also to avoid the cross contamination with pathogens from nearby farms, which improves biosecurity.

Ponds for farmed animals should have separated inlets and outlet canals, so that water supplies and effluent are not mixed. Water inlets to each ponds should be screened to prevent the entrance of unwanted animal species/predators.

The main farm inlet (Fig. 37) abducts water from outdoor. It must be always filtered (screen filter, or also sand filter) to control any source of contaminants from outside. The reservoir has an important role to store water and to keep it for adequate period of time under the sun. The lack of farmed fish in the reservoir helps to break any cycle of transmission of possible parasites/pathogens that may have escaped the filtration and to destroy the chemical compounds that may be present in the water through the sun's UV rays.

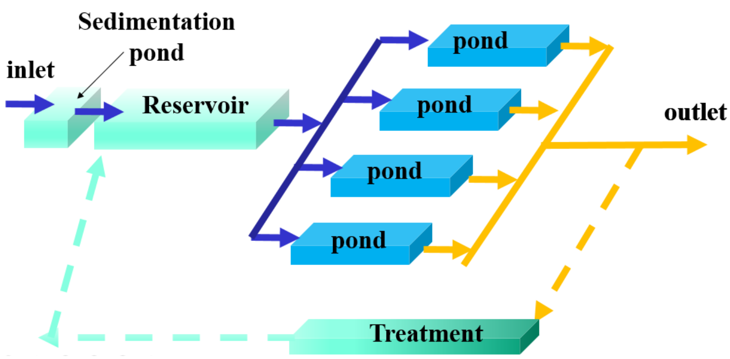

Fig. 37 layout of a bio secure farm

In order to break the cycle of transmission different species of fish from those farmed in the grow-out ponds can be stocked. They can be mainly carnivorous fish that can control any recruitment escaping the farmed pond to avoid any possible transmission of pathogens along the farm. Such "control" fish can be stocked in the treatment area and also in the reservoir.

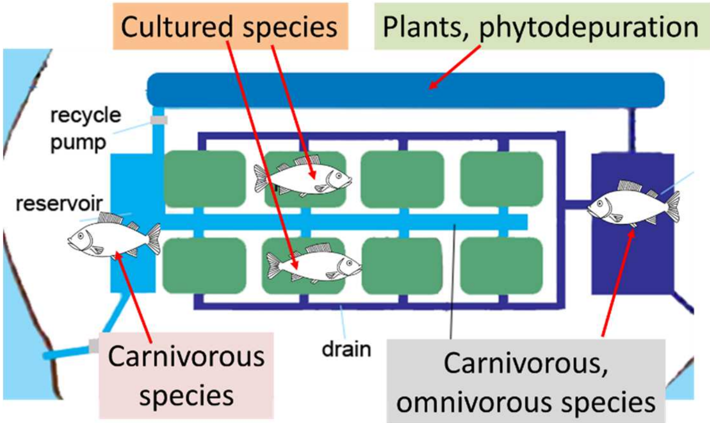

Fig. 38 A layout of a closed farm with growout ponds (in green) for the desired species, and omnivorous/carnivorous species stocked in the reservoir, treatment and sedimentation ponds. Carnivorous species would control escapees and juveniles that could possible transmit diseases to other ponds.

Ponds must be of adequate size to allow the emptying of the water body for maintenance and sterilization at the end of the production cycle.

Pond maintenance

Drying the pond helps to remove any possible source of infection and process wastes. Expose the soil to the air favour oxidation of the organic wastes accumulated during the farm period. The dry conditions and the effect of the UV light from the sun also help to sterilize the bottom and have a better control of the health during the successive farm cycle. The ponds should be dried up towards the last period of the dry season leaving sufficient time (2-3 weeks) to help to get rid of wastes and create a good nutrient pool for the successive crop.

Application of lime (calcium hydroxide $Ca(OH)_2$ or calcium oxide CaO) on the soil at rates of 120-250 kg/acre, manually broadcasted. Quantity increases in case of acidic soils (pH 6), in this case the quantity may be doubled.

Fig. 39 drying and liming the pond to improve health

Pond fertilization

Always beware to pour new water in each pond by applying a screen filter at the inlet to control any accidental presence of parasite larvae, eggs, predators.

Fertilization helps ponds to improve their natural food that will nourish the aquatic animals. Initial fertilization could be applied as chicken manure with a rate of as 200-800 kg/acre/year depending on the fertility of the soil (but beware of hormones or antibiotics in unprocessed chicken wastes). Add chemical fertilizers at least one week before stocking the fish. Application of 10 kg/acre of Nitrogen and 2.5-6 kg/acre of Phosphorus.

As a rule of thumb ongoing fertilization during the farming of animals in semi-intensive systems should be:

- Chicken manure applied as 400-800 kg/acre/week
- Urea + TSP 25 kg/acre/week + 25 kg/acre/week

The fertilization effect can be successively monitored by using the Secchi disk and comparing the measurements obtained against the table below:

- < 20 cm too green → stop fertilization and reduce feeding for 1 week
- 20-30 cm very green → stop fertilization and reduce feed
- 30-40 cm appropriate → normal fertilization and feed
- 50 cm low plankton → increase fertilization

It is important to remember that too green water can pull the DO up to 12 mg/L, which oversaturates the water and can cause bubble disease in fish, therefore paddlewheels can help to disperse such excess of oxygen during this peak of oxygen occurring daytime.

Use or probiotics

They are microorganisms and/or enzymes that are naturally present in nature that have a positive effect on both pond and fish. Probiotics are normally commercialized in almost any country, although their price may be high depending on the distribution system. In many cases the micro-organism involved are also used in agriculture to treat fungal or bacterial diseases in plants.

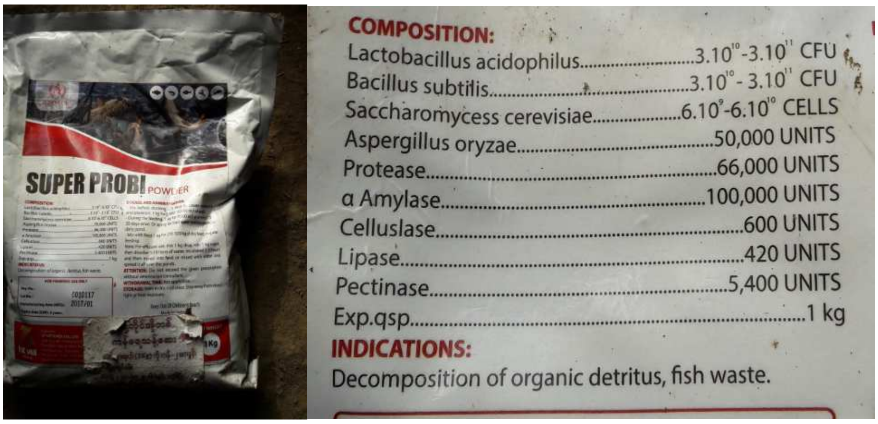

Fig. 40 the composition of a commercial probiotic product used in aquaculture. It contains strains of *Bacillus subtilis*, *Lactobacillus acidophilus* a probiotic found in yoghurt and *Saccharomyces cerevisiae* commonly known as baker's yeast

Claims about the potential benefits of probiotics in aquaculture ponds include:

- enhanced decomposition of organic matter at the bottoms
- Reduction in nitrogen and phosphorus concentrations;
- better algal growth;

- greater availability of dissolved oxygen
- Less cyanobacteria (blue-green algae)
- control of ammonia, nitrite, and hydrogen sulphide
- lower incidence of disease and greater survival
- greater shrimp and fish production

Farm Biosecurity

Deterrents against birds that can either predate the fishes or carry parasites in their faeces that can harm farmed animals. This is particularly important for more intensive systems, where high densities of fish are stocked in small ponds.

Fig. 41 birds nets topping a nursery pond

Developing strategies for biosecurity

Disease is always the result of the interaction between the animal, the pathogen and the surrounding environment. If the animal is weak it is very likely that it can get sick, because it is easier for the pathogen to bypass the natural defences of the animal. Good management practices are therefore fundamental to avoid the deterioration of the environment and to avoid the weakening of the defences of the animals. Adequate environmental control is thus necessary to reduce stressing condition for the fish that could lead to the outbreak of the disease.

Diseases are caused from both abiotic and biotic factors. In the previous part of this manual, water quality parameters have been already described as important co-factors to avoid mortality. In addition, control of environmental conditions, such as safe water with filtration, improvement of shadow to avoid hot temperatures into the water, build deep water ponds to avoid temperature fluctuations can have positive impact on the reduction of the risks of infections.

The improvement of the biosecurity by transforming pond in closed systems is another important aspect to minimize risks of cross infection with other neighbouring farms. In the past most of the outbreaks devastated the production of many countries for the simple reason that farmers did not comply with bio-safe import regulations by bringing in diseased stocks from abroad and by ignoring simple but fundamental rules of hygiene and biosecurity.

Different groups of pathogens that cause fish disease are fungus, bacteria virus, protozoa and parasites. All of these infectious agents can easily enter into the farm from the environment, when adding new fish or new water, or could have present into the farm but in a not harmful conditions due to unfavourable environmental conditions.

Prevention is by far the best way to prevent disease in fish. Daily observation of fish, quick disposal of dead fish or any waste that can favour bacterial growth is fundamental. Also monitoring for disease allows the pathogen, if present, to be treated quickly to prevent more fish from being infected.

Farm outline and biosecurity

Structural changes in farm design are important to improve water quality and biosecurity. A summary of good practices is as follows:

- The water inlet and outlet of each pond must be separated and flow into two different canals.
- Water should be taken from a clean canal or water body and ideally sand filtrated to be stocked into the reservoir
- The use of reservoirs is encouraged to store water when it is not available or when there are reasonable risks that water could be contaminated by chemicals or pathogens from other farms.
- Ponds should be supplied with protection against bird predation and contamination with parasites form the faeces. In intensive shrimp farms crabs are potential risk factors of diseases, prevention is made by fencing with 1-1.5 ft. plastic sheets the ponds in order to build a slippery wall that is impossible for them to bypass.
- Inlet of water to the pond must always be filtrated against larvae fine screens are necessary.
- The design of fish farm as a closed system improves sensitively the biosecurity. In closed system the water circulates between rearing ponds, treatment pond and reservoir to:
    - Let wastes be reduced by other aquatic organisms without polluting outside environment/water
    - Control vectors of diseases. Parasites have a cycle of few days, if they do not find the host they eventually die.

- Kill viruses or potential pathogens by aging process. The sun is for example a good source of UV light, which is a sterilizing agent.
- The stocking of alternative species of fish in the treatment pond and reservoir, help to break the cycle of transmission from animal to animal. Carnivorous fishes also help to kill the possible escapees from each pond thus guaranteeing the complete control of the water.

In addition good management practice suggest the need to empty the pond at the end of each production cycle to expose the soil to oxygen, mineralize the soil to get rid of organic wastes, lime to sterilize the bottom and control possible predators or diseases vectors.

Buying Fingerlings

Fingerlings should be of best quality to guarantee optimal growth performances. Be always sure to get fingerlings from a reliable seller who can guarantee for health status, since diseased fish are the main cause of infection in farms. Therefore it is important to get a health certificate when buying, especially from abroad, and to comply with all the safety regulations to avoid damages to own and neighbour farms.

According to main International Regulations: fish can be sold for farming purposes 31 days after an increased mortality event or an outbreak event is finished. Fry and fingerlings must be disease-free and should comply with the OIE Codes of Practice (OIE Aquatic Animal Health Code, 2016[8].

- Transport should avoid any stress to fish that may reduce their resistance against pathogens.
- Avoid stress by using different types of water during transport
- Avoid temperature fluctuations
- Be aware of the sun/heat warming the fish bags too much, which can cause stress or even mortality
- If using big tanks for transport be sure to have sterilized all the equipment before using. Use sterilizing products that are not harmful to fish. If using beach/chlorine be sure not to leave any residues that may put in danger the fish

Entrance check

Suspected diseased fish should be refused or removed. The remaining stock should be quarantined in a separated area and observed for some days to see if there are any sign of diseases. Animals are kept for 15-20 days and then released if no signs of diseases are seen.

Dead fish should be disposed immediately in a sanitary manner to avoid the spread of disease and the cause of death should be investigated.

It is recommended to apply an entrance check every time a consistent amount of fingerlings gets into the farm.

The check-table must contain the following information:

- Date
- Furnisher name and address
- Number or kg of fingerlings requested and size range
- Lot number (if present on seller certificate)
- Destination (i.e. pond number 3)

[8] OIE - World Organization for Animal Health Aquatic Animal Health Code 2016. Online publication. http://www.oie.int/en/international-standard-setting/aquatic-code/access-online/

- Dead fish during transferring operations (number or weight)
- Effective fish number

Several treatments can be used to disinfect fish before transferring in ponds. Potassium permanganate ($KMnO_3$), formalin, copper sulphate or other substances must be allowed by National Competent Authority and used according to the instructions.

Bath salts is also effective against some specific pathogens or parasites. A dosage can be as follow:

- 1kg salt/100L (10 ppt), for 20-30 minutes, then keep fish for 5-7 days in 2g/L salt (2 ppt)

Health management

Maintaining the health of fish needs good practices. It is important to remember that prevention is the best of the treatments because the use of any drug or chemical is expensive

Healthy stocks are maintained through good farming conditions, environmental management, optimal nutrition, reduced stress, and by avoiding any possible risk of brining in pathogens.

The primary goal is to avoid any possible contact between the pathogen and the host, this can be obtained with:

- a pathogen-free water supply
- the use of certified pathogen-free fish stocks
- the use of quarantine at entrance
- strict attention to sanitation to avoid contamination from other sources

Careful management eventually bring economic advantages in the reduced use of treatments with drugs or chemicals to treat diseases.

Vaccines

Whereas possible use of vaccination is also suggested to provide preventive protection against specific viral as well as bacterial diseases. Fish can be economically and conveniently vaccinated while still very small. Protection conferred by vaccination is often durable thus eliminating the need to treat diseased aquatic animals. The decision for the immunization should be taken according to the risks of infection based on the national monitoring system.

Drugs

While vaccines play an important role in disease prevention, at times drug treatments may be required. It is essential that these drugs are used judiciously and with thorough understanding of how they can be safely used.

Antimicrobials are available under different formulation and commercial names depending on the countries, however the most common are oxytetracycline (e.g. Terramycin® for Fish, oxytetracycline monoalkyl trimethyl ammonium) and a potentiated sulfonamide (e.g. Romet-30®, ormetoprim: sulfadimethoxine).

These drugs can only be administered through feed in a specific feed formulation and under veterinary supervision.

After treatment it is fundamental that the withdrawal time indicated by the product is observed. withdrawal time indicates the period between the last administration of the drug to the aquatic animal and the time when the aquatic animal can be harvested and eaten.

The withdrawal time ensures that no harmful drug residues are present when the animal is harvested for human consumption. It is also important in case of export of fish, since many importing countries carry out inspections for the presence of drugs in the fish, which eventually results in loss of products if the veterinary service in the receiving country denies the entry to the products.

Common diseases

A brief summary of common diseases occurring in aquatic animals is grouped in five main categories: bacteria, virus, parasitic, protozoa and virus. For each disease a description of the main symptoms and cause agent is specified[9].

Recognizing diseases

Diseases may occur even if all the precautionary strategies are put in practice. A good farming management keep monitoring on any sign of diseases in the fish stocked in the ponds. Early detection of problems can make a huge difference because prompt treatments can reduce losses. Some signs of diseases and behavioural changes are listed below:

External signs of disease:

- ulcers on body surface, discoloured patches, white or black spots
- ragged fins, exposed fin rays
- gill and fin necrosis and decay
- abnormal body configuration, twisted spine, deformed jaws
- extended abdomen, swollen appearance
- cotton-like lesions on the body
- swollen, popped-out eyes (exophthalmia)

Fig. 42 Fish ulcers (source: Researchgate)

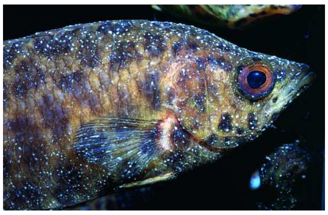

Fig. 43 white spots (source: JBL)

Fig. 44 Ragged fins (source: fishkeepingadvice)

Fig. 45 fin necrosis (source: Researchgate)

[9] Source: Noga, E.J. 1996. Fish disease, diagnosis and treatment. St. Louis, USA, Mosby Year-Book inc. 367 pp. (modified)

Fig. 46 gill necrosis (source: marinescience.blog)

Fig. 47 bent spine (source: fishlore)

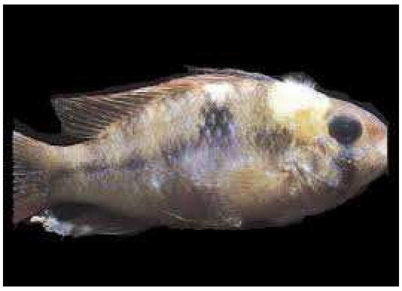

Fig. 48 cotton-like lesions (source: massmind)

Fig. 49 swolled abdomen (source: Researchgate)

Fig.50 fish popped eyes (source: Researchgate)

Fig. 51 black spot (source: michigan.gov)

Behavioural signs of disease:

- poor appetite, changes in feeding habits
- lethargy, different swimming patterns, listlessness
- odd position in water, head or tail down, difficulty maintaining buoyancy
- fish gasping at the surface
- fish rubbing or scraping against objects

Bacterial diseases

Columnaris

Also called peduncle disease, fin rot, cotton wool disease, black patch necrosis

Symptoms: reddening and erosion of skin turning into shallow ulcers and necrosis, necrosis of gills, release of yellowish mucus from the lesions.

Causes: main agent Flexibacter columnaris. Concurrent causes from acute stress, increase of temperatures, low oxygen, and nitrite. Above 15 °C increases pathogenicity.

Remedies: prolonged immersion in potassium permanganate to treat fish initially and increase appetite to let them eat medicated feed. Immersion in copper sulphate. Antibiotic treatment (oxytetracicline, nifurpirinol). Eliminate the underlying causes.

Dropsy

Symptoms: infection of internal organs leading to fluid accumulation in the body. The fish appear bloated.

Causes: various bacteria, although it can be caused by parasites or a virus. Concurrent causes are also weakened fish and inadequate water/environmental standards.

Remedies: treatment of fish with medicated feed containing antibiotics (chloramphenicol, tetracycline). Elimination of water/environmental causes.

Fig. 52 Columnaris (source: fishlab)

Fig. 53 Dropsy (source: fishkeepingadvice)

Fin rot

Symptoms: damaged fins with fin ray exposed, erosion, loss of colour, ulceration and bleeding. Internal septicaemia.

Causes: bacterial infection from different agents, but Pseudomonas spp. more recurrent. Poor water conditions, bullying from other fish. Often pathogenic at low temperatures.

Remedies: identify the cause(s). Treat the fish in a separate tank by providing medicated feed with non-resistant antibiotics (chloramphenicol or tetracyclin) or dissolve the antibiotic directly in the water. Keep separated until full recovered.

Streptococcosis

Symptoms: acute haemorrhages on body, popped eyes. Presence of sanguineous liquid in peritoneal cavity.

Causes: Streptococcus spp.

Remedies: treatment with antibiotics (oxytetracycline erythromycin, ampicillin).

Fig. 54 Fin rot (source: about-goldfish.com)

Fig. 55 Streptococcus (source: semanticscholar.org)

Tubercolosis

Symptoms: emaciation, lethargy, lack in appetite, hollow belly. Skin presents ulcer, loss of scale and fin erosion. Appearance of yellow or dark tubercles on the body. Presence of 1–4 mm white nodules in internal organs especially on kidney and spleen.

Causes: the bacteria responsible are Mycobacterium spp. but overcrowding, poor water quality and susceptible fish species are supplementary causes. Ingestion is the most common transmission factor. Encysted bacteria can survive two years in the environment.

Remedies: extended treatment with erythromycin, streptomycin or kanamycin and Vitamin B-6 or elimination of the fish. Attention is required when handling as the disease may be transmitted to people.

Vibrio

Symptoms: skin haemorrhagic with reddening spots in the lateral and ventral part of the fish, swollen lesions turning in ulcers releasing pus. Systemic infection in kidney and spleen. Eye lesions such as eye cloudiness, ulceration, popped-out eyes and eventually organ loss. Additionally anorexia and depression.

Causes: various type of Vibrio spp., more common in brackish-water and tropical fish. Increased incidence with higher temperatures. Concurrent factors in stress, crowding, organic pollution. In salmonoids, *V. anguillarum* outbreaks appear in temperatures below 5 °C.

Remedies: timely treatment with antibiotics (oxytetracicline, sulfonamides) due to the very fast course of the disease. Reduction of stress is fundamental for long term control of the disease. Attention required when handling, as the disease may be transmitted to people.

Fig. 56 Tubercolosis (source: aquarium-pond-answers)

Fig. 57 Vibrio (source: backend. orbit.dtu.dk)

Fungal diseases

White cotton saproleigna

Symptoms: white, brown or red cottonish growth on fish surface, expanding. Ocular lesions as cloudy eyes causing blindness and loss of the organ.

Causes: *Saprolegnia* spp. often as an opportunistic agent following other infections and overall fish weakness. Concurrent causes in acute stress, temperature drop, transport stress.

Remedies: prolonged salt bath or formalin bath, treatment of eggs with hydrogen peroxide or prolonged immersion in methilene blue. Lesions may be treated with cloth soaked with povidone iodine or mercurochrome.

Protozoan diseases

Coccidiosis

Symptoms: intestinal infestation and enteritis, epithelial necrosis. Lesions on/in internal organs such as liver, spleen, reproductive organs and swim bladder.

Causes: Coccidia belonging to different families.

Remedies: use of coccidiostat monensin, sulfamidimine (1 ml in 32 litres water; repeated weekly) or amprolium.

Fig. 58 Saproleigna (source: practicalfishkeeping.co.uk)

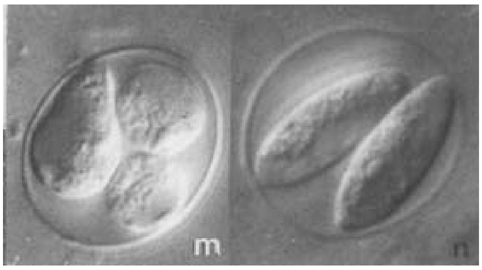

Fig. 59 coccids (source: FAO)

Hexamitosis

Symptoms: occurrence of parasite in intestine and gall bladder or other organs in more advanced cases. Presence of abdominal distension and white, mucous excrements followed by behavioural disorders such as fish hiding in corners with head down and/or swimming backwards, progressive reduction of head volume above the eyes and darkening of body.

Causes: Hexamita spp. Spironucleus spp. flagellate protozoa attaching the intestinal trait. Affects debilitated and stressed animals.

Remedies: use of Metronidazole both in the feed (1 %) and in the water (12 mg/litre). Addition of magnesium sulphate as a cathartic. Increase temperature and improve environmental conditions.

Ich/white spot

Symptoms: small white cysts (up to 1 mm) covering the body of the fish giving an appearance of salt grains that emerge, mucous skin, skin erosions. Behavioural disorders seen as lethargy, loss of appetite, and body rubbing against walls in the attempt to remove the parasite.

Causes: Ichthyophthirius multifiliis.

Remedies: the parasite is susceptible of treatment during the free-swimming stage of juveniles (theronts) following the adult stage on the fish (trophont) and the production of cysts (tomont) that fall on the bottom. Treatment with salt bath or formalin bath every week until cured. Maintain water temperature above 30 °C for 10 days. Raising the temperature from 21–26 °C shortens the cycle of the parasite from 28 to 5 days making the treatment period in curative bath shorter.

Trichodina

Symptoms: a wet mount (microscopy) of skin scraping will show the parasite. A grey film on skin and gills, along with an excess of white mucous secretion. Anorexia and loss of condition in heavily infested fish.

Causes: saucer-shaped protozoan parasite that attaches to gills and the body surface of the host fish. Often found in poor water quality and overstocking.

Remedies: formalin or potassium permanganate bath. Salt or acetic acid bath immersion (freshwater protozoa only).

Fig. 60 Hexamitiasis (source: Sciencedirect)

Fig. 61 Ich (source: Fishlab)

Velvet/Dust

Symptoms: brownish dust covering the body and/or the fins. Respiratory discomfort (out-of-breath) with quick gill movement due to presence of parasite on the gills, cloudy eyes. Formation of cysts that discharge free infective parasites.

Causes: Piscinodinium spp. a parasitic skin flagellate that binds to the host.

Remedies: disease is highly contagious and fatal. Raising temperatures at 24–27 °C speeds up the cycle for treatments. Leaving the system with no fish for two weeks to remove the protozoan. For heavy infestation a bath with 3.5 % salt for 1–3 minutes is effective to remove the trophonts. Alternatively, treatment with copper sulphate at 0.2 mg/litre in a separate tank, repeated as necessary. Copper can bioaccumulate and cause toxicity.

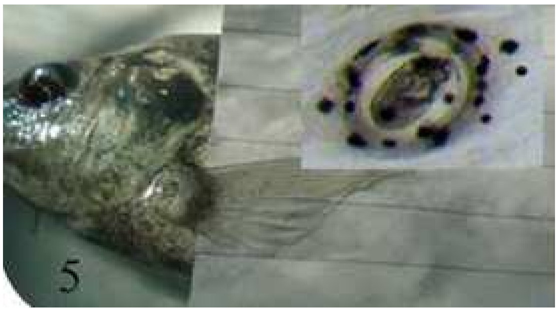

Fig.62 Thricodina (Source: Researchgate)

Fig. 63 Velvet (source: tropicalbettafish)

Parasitic diseases

Anchor worm, lice

Symptoms: presence of parasites on skin, gill, mouth. Erosion and ulceration. Red spots on skin that can raise up to 5 mm.

Causes: copepods of various origin, introduced from the wild.

Remedies: identifiable with magnifying lens, extended treatment in salt (freshwater species). Also hydrogen peroxide, formalin and ivermectin are remedies for lice.

Flukes

Symptoms: scraping on tank walls, release of mucus from gills, fast gill movement, gill and fins damages. Paleness, quick respiration and flopping fins.

Causes: flatworms about 1 mm long infesting gills and skin. Detectable with magnifying lens.

Remedies: treatment of 10 to 30 minute bath in 10 mg per litre of potassium permanganate in a separate tank (freshwater parasite only). Salt bath (freshwater parasite only). Formaline or copper bath.

Fig. 64 anchor worms (source: pondaquariumproblemsolver.co.uk)

Fig. 65 flukes (source: fishpathogens.net)

Leeches

Symptoms: presence of parasites on the skin creating small red or white lesions. Heavy infestations lead to anaemia.

Causes: external parasites mainly introduced from wild.

Remedies: avoid introduction of raw plants or snails, bath in salt solution, use of organophosphates.

Nematoda

Symptoms: progressive loss of weight, lethargy, void bellies and accumulation of parasites around the anus. Colonization of viscera with 0.6–7.0 mm worms in the intestine.

Causes: threadworms infesting all over the body but are visible when they concentrate at the anus. Infestation occurs with introduction of wild or pond fish.

Remedies: medicated feed with fenbendazole oral, levamisole oral

Fig. 66 Leeches (source: Redoubtreporter)

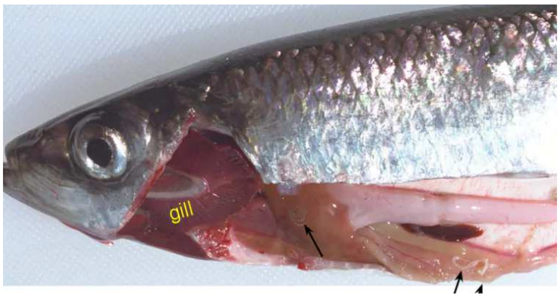

Fig. 67 Nematodes (source: cbc.ca)

Viral diseases

Spring viremia of carp

Symptoms: Swim bladder inflammation. Acute mortalities in spring and early summer. Decreased swimming ability, dark skin: haemorrhages on skin, vent, gills, peritonitis, enteritis, inflammatory exudate and haemorrhage in muscle and viscera

Causes: *Rhabdovirus carpio*, trasmitted by Argulus (small crustaceans) and leeches

Remedies: n.a.

Grass carp rheovirus

Symptoms: Popped eyes, haemorrhage in gills, mouth, fins, viscera. Disease at 25-30C, most severe in your fish.

Causes: Haemorrhagic virus of grass carp

Remedies: n.a.

Grass carp virus CIVH 33/86

Symptoms: Epitelioma. Milky white to grey plaques up to 2mm thick may cause scarring, retard growth. Lead to skeletal deformities, papillomatous skin. Lesions develop in low temperatures (winter/spring) and regress with high temperature.

Causes: *herpesvirus cyprini*

Remedies: n.a.

Chromide cichlid anemia

Symptoms: Pale, weak, cachexic

Causes: Iridovirus-like

Remedies: n.a.

EUS viruses

Symptoms: Striped snakehead. Isolated in viscera. Little evidence of viral causes.

Causes: Rhabdoviruses

Remedies: n.a.

Fig. 68 Herpesvirus (source: edis.ifas.ufl.edu)

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Annex 1
Quick water quality reference

➢ Ammonia	Values to zero – water exchange, chloride, oxygenation
➢ Nitrite	Values to zero – water exchange, oxygenation
➢ Nitrate	2-20 ppm, add fertilizer/urea to promote algal growth
➢ Phosphorus	Limited, add fertilizer/TSP to promote algal growth
➢ pH	Towards 7. Add lime and/or calcium carbonate to raise and eventually increase also alkalinity
➢ Oxygen	Measure at dawn, and see if fish gasp at the surface. aeration with paddlewheel also to digest wastes
➢ Salinity	According to fish species farmed
➢ Plankton	Measured with Secchi disk, if too low add fertilizer
➢ Temperature	Ideal for the species. Add shadow if too sunny or hot

Tools

➢ Ammonia	Test kit
➢ Nitrite	Test kit
➢ Nitrate	Test kit
➢ Phosphorus	Test kit
➢ pH	Test kit, test strips, pH meter
➢ Oxygen	DO meter, or observe presence of gasping at dawn
➢ Salinity	Refractometer
➢ Plankton	Secchi disk
➢ Temperature	thermometer