MANAGING WATER QUALITY FOR AMPHIBIANS IN CAPTIVITY

Kay Bradfield
Herpetology Department
Durrell Wildlife Conservation Trust

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NOTES ABOUT AMPHIBIANS & WATER QUALITY

- Amphibian eggs do not have a shell, which means that they are essentially part of the surrounding aquatic environment, and developing embryos are subjected to whatever water quality problems are present. Amphibians also have highly permeable skin, and they absorb all or most of their moisture through this (in anurans, water intake is primarily through the "ventral patch" or "drink patch", located on the posterior portion of their belly). They also absorb a substantial proportion of their oxygen through their skin. These ties to aquatic environments mean that they are particularly sensitive to changes in water quality and quantity.

- As is the case for most freshwater vertebrates, the plasma of aquatic amphibian life history stages is markedly hyperosmotic and hyperionic relative to the surrounding environment. These osmotic and ionic gradients are the driving force for the continual osmotic uptake of water and loss (through diffusion) of plasma ions. Water is taken up across the gills, skin and / or gut. To maintain ion balance, they excrete large quantities of dilute urine, and actively transport ions across external epithelia (potential routes of active uptake include the gills, skin, gut and buccopharyngeal epithelium) (Ultsch *et al.* 1999). For example, amphibians can absorb sodium through their skin in dilute pond water (Prosser 1973 in Whitaker 2001).
- Whitaker (2001) notes that some amphibian species can absorb specific ions from food in their digestive tract, while other species are dependent on absorption from the water.
- 'Typical' tadpoles have CaCO3 deposits in their endolymphatic sacs; these are important for calcification of the skeleton (Ultsch *et al.* 1999). *Rana catesbeiana* tadpoles developed skeletal deformities similar to spindly leg syndrome when reared in water that contained less than 4mg/l calcium (Marshal *et al.* 1980 in Whitaker 2001). In one ranid species, body calcium ion concentrations increased almost three-fold during premetamorphic and metamorphic stages, probably due to development of the limbs and increased calcification of the skeleton (Ultsch *et al.* 1999). This may have implications for water chemistry in captivity.
- Many freshwater habitats around the world are actually acidic due to naturally occurring humic acids or the biological activity of *Sphagnum* (including rivers, coastal plains, boreal peat bogs, heathlands, swamps, and ponds), and amphibians, as a group, are much more tolerant of low pH than fishes. Within anuran species, adults are the more tolerant than eggs and tadpoles, and tadpoles are more tolerant than eggs (Ultsch *et al.* 1999). The primary toxic effect of low pH is disruption of sodium and chloride ion balance (acute exposure to lethal pH inhibits the active uptake of sodium and chloride ion while simultaneously stimulating the passive loss of sodium and chloride ions – death occurs when body sodium ion concentration is reduced by approx. half; chronic exposure to sublethal pH generally causes a 20% decrease in body sodium ion concentration and stimulates compensatory mechanisms to help maintain ion balance; exposure to low pH acts in a similar manner to other salt-depleting environmental conditions such as distilled or soft water) (Ultsch *et al.* 1999).
- Another point that should be kept in mind is that, for a given species, different life-history stages may prefer / require waters with quite different compositions.
- Clinical signs indicative of poor water quality are frequently non-specific, and include lethargy, anorexia, loss of coordination and / or equilibrium, increased respiratory rate, and color change (Whitaker, 2001).

IMPORTANT POINTS

- In order to provide appropriate water chemistry in captivity, it is essential to know what the water chemistry is in the waterbodies the species inhabits in the wild!! This is important in terms of animal welfare and best-practice husbandry when animals are kept in captivity for any purpose, but is critically important for conservation breeding for release programmes (note that with breed for release programmes, the water chemistry of both the collection and release waterbodies need to be taken into consideration). While this is a very basic point, and one that is considered essential in fish keeping, it is one that has been largely over-looked to date with amphibians.

- Aquatic system management is best described as a synergy of disciplines: husbandry practices, aquatic system (also referred to as 'life support') design and operations, and quality assurance through routine water quality testing.
- It is advisable to **set up enclosures two to six weeks prior to introducing animals**. This will allow natural bacteria to become established in the substrate / filter and plant growth (if present) to become lush.

SETTING AQUATIC SYSTEMS UP – MATERIALS

- Metallic pipes and containers should be completely avoided as heavy metals can be lethal to amphibians at higher levels (*e.g.* Brand *et al.*, 2009; Lefcort *et al.*, 1998; Garcia-Muñoz *et al.*, 2009), while sublethal effects can include larval deformities (Chen *et al.*, 2006), reduced larval development time (Brand *et al.*, 2009), increased larval development time (Chen *et al.*, 2006; Lefcort *et al.*, 1998; Garcia-Muñoz *et al.*, 2009; Parris & Baud, 2004), reduced growth rates (Garcia-Muñoz *et al.*, 2009), altered larval behaviour (Garcia-Muñoz *et al.*, 2009; Lefcort *et al.*, 1998), immuno-suppression, and reduced reproductive output (see review in Carey & Bryant, 1995). Note that many houses / buildings still have galvanised or copper water pipes → ***Solutions***: ideally, replace metal pipes with plastic; run the tap fully open for five - 10 minutes before using the water in order to wash out any heavy metal ions that have accumulated in the pipes; some aquarium water conditioners precipitate out heavy metals so that they can then be removed by the filtration system; RO filters remove heavy metals.
- Ideally, only glass and food- or aquarium- grade plastics should be used in the set up of amphibian aquaria / enclosures. If the use of other plastics (*e.g.* plant pots, buckets, storage boxes or other containers, waste water pipes, etc.) is unavoidable, these should be repeatedly filled, left for 24 hrs., emptied & re-filled or thoroughly run through to ensure that any chemicals that may leach out of the plastic have done so prior to use with amphibians.

SETTING AQUATIC SYSTEMS UP – WHAT SORT OF SYSTEM??

- There are two types of aquatic systems that are commonly used to house amphibians in captivity: semi-closed and open (Odum & Zippel, 2008).

Semi-closed systems

- Semi-closed systems are the most commonly aquatic system for amphibians (Odum & Zippel, 2008); these are the 'traditional' aquarium systems that use filtration systems and regular, partial water changes to maintain water quality.

Open systems

- Open systems are flow-through systems; water is continually entering the system at one point and leaving it another point, creating a flow that flushes wastes, excess food, etc. from the enclosure.
- Provided that the rate of influent flow is adequate, good water quality can be maintained without any filtration system, as water does not stay in the system for long.
- ***Advantages of open systems:***
    - water quality is not only high, but is constant (*cf* fluctuations in various parameters that occur as a result of the aquarium inhabitants living in the water (*i.e.* gradual changes to these parameters) and the regular partial water changes (*i.e.* abrupt changes) required in semi-closed systems),
    - they can be quite simple and relatively low maintenance compared to semi-closed systems,
    - potentially pathogenic organisms should not build up in aquaria as they are constantly washed out with the effluent water.
- ***But***, they do require a continuous supply of appropriate (in terms of both quality and temperature) water.

SETTING AQUATIC SYSTEMS UP – WHICH WATER??

Tap water - municipal water supplies

- As mentioned in sections above, municipal water supplies can contain chlorine, chloramines, and / or heavy metals, so must be tested for these (in addition to pH, KH, GH, etc). Refer to relevant sections above for details on how to deal with chlorine / chloramines and / or heavy metals.
- The chemical properties of a water supply can vary over time (*e.g.* bacteria levels tend to be higher in summer than winter, so more chlorine is often added to water supplies during summer; heavy rains can cause the hardness of a water supply to decrease as reservoirs fill). Also, some counties / regions cannot always meet the demand for water themselves, and so water is brought in from adjacent regions when necessary; this water may have very different chemical properties to the 'normal' tap water in an area.

Tap water – bores / wells

- Bore / well water can be super-saturated with nitrogen and / or carbon dioxide as it leaves the tap; as a result, the pH will be suppressed and will increase steadily as the nitrogen and / or carbon dioxide gas disperses, subjecting animals to potentially very stressful shifts in pH. →
Recommendation: Prior to using bore / well water with amphibians, test the pH at 0, 12, and 24 hours after it leaves the tap; if the pH increases during this period, then there is an issue with super-saturation. Do not use super-saturated bore water straight out of the tap, instead aerate it for 24 hours (*e.g.* in a bucket with airstones) before use so that any gas disperses and the pH stabilises. If this is not possible, agitate the water as much as possible while (*i.e.* use a hose head) / immediately after filling water dishes, etc.
- This may be a particular problem with flow-through rain chambers, particularly when the 'rain' is only turned on for several hours / day. →

Recommendation: If this cannot be avoided, a pH probe with a data logger should be used to determine exactly what is happening to pH over 24 hours in the system (it is difficult to predict what will be happening – it may be gradual or abrupt shifts, may be quite large or reasonably small changes, etc.).

- Bore / well water can also contain hydrogen sulphide and / or be devoid of oxygen; again, aerating the water for 24 hours prior to use will disperse the potentially lethal hydrogen sulphide and oxygenate the water.
- Bore / well water should be tested for its heavy metal content, hardness and pH (in areas of limestone bedrock, it may be too hard / alkaline for use with amphibians), and phosphates and nitrates (from fertilizers that seep into the aquifer). Refer to relevant sections above for details on how to deal with heavy metals and / or inappropriate water hardness / pH.
- In coastal areas, bore / well water should be tested for salinity.

Bottled water

- While some brands of bottled water may be suitable for use with particular amphibian species, the pH, hardness, and chlorine level of the water must all be tested first; spring water that has been pumped up through bedrock can be too alkaline / hard for use with most amphibians, and some brands are nothing more than tap water.
- In the US, the Natural Resources Defense Council found that one in three bottled water samples contained contaminants such as coliform bacteria, synthetic organic chemicals, or arsenic (*cited in* Odum & Zippel, 2008).

Rain water

- Rain water usually has a pH of approximately 6.9 or 7.0, but the problem is that it has very little buffering capacity, so the pH will drop quickly if there are high levels of nitrification in the system.
- If collecting rain water for use with amphibians, copper, galvanized, or asphalt roof surfaces can contaminate the water with metals and other chemicals, and if there are native amphibians living in the gutters or using the collection roof, this poses a disease risk for your collection species.
- If using rain water, pass it through activated carbon prior to use in order to remove volatile organic compounds (*e.g.* jet fuel, oil, some pesticide residues).

Water from natural waterbodies

- In some situations, it may be possible to use water from ponds, lakes or streams, however, it is essential that the drainage area for the waterbody does not include agricultural, industrial or urban areas, and that the water is screened for *B. dendrobatidis* and any other pathogens of concern prior to its use (and that water is screened each time it is collected).
- Potential advantages of using clean 'natural' water are that it will contain a diverse array of protists, invertebrates, algae, etc. for larval or aquatic amphibians to eat, and that water quality may be higher than that of tap or bottled water.
- In biosecure facilities, however, 'natural' water would have to filtered and disinfected prior to use.

Reverse-osmosis filtered (RO) water

- Reverse osmosis is the process of forcing a solvent from a region of high solute concentration through a semi-permeable membrane to a region of low solute concentration by applying a pressure in excess of the osmotic pressure; in this way, impurities such as salts are filtered out. ***RO filters do not remove some smaller compounds (e.g. some nitrates, phosphates and silicates) from water***, however. → A de-ionising (DI) filter can be used in conjunction with the RO filter to remove these compounds if necessary; DI filters use chemical resins, and care must be taken to ensure they are replaced as necessary.
- RO water is virtually free of solutes and too pure for most amphibians (the exceptions are species that live / breed in pure rain water, *e.g.* species that use phytotelms, including some dendrobatids; Odum & Zippel 2008).
- Its high purity (low level of solutes) means that, in an attempt to reach osmotic equilibrium, water will move from the relatively pure surrounding water into the more concentrated tissues of an amphibian. Over time, this may result in oedematous (bloated) animals and impaired kidney function. To compensate for the water's purity, salts and minerals should be added back to the RO water to create a solution that is isotonic with amphibians (refer below).
- Pure (*i.e.* not remineralised) RO water is ideal for misting systems for exhibits where mineral deposits on the viewing glass are not desired. However, other sources (pools, water dishes, etc.) of balanced water need to be available to amphibians in these enclosures to prevent internal osmotic imbalances.

Reconstituting RO water

- Depending on the quality and water chemistry of the water supply, and the pH and alkalinity you want to achieve in a system, tap water can sometimes be used to reconstitute RO water. The proportion of tap water to RO water will depend on the species requirements in terms of pH and alkalinity, and the chemistry of the tap water, and is dynamic (*i.e.* adjusted as necessary to maintain appropriate water chemistry). The benefits are that it is cheap and easy.
- It is not always possible to use tap water to reconstitute RO water (depending on the tap water itself, and the species requirements).
- Specific remineralisation formulations can be purchased (from pet shops, *e.g.* Kent Freshwater RO Right, or from specialist manufacturers who make blends to meet specific criteria, *e.g.* Growth Technology, a hydroponic gardening supplier). There are various recipes for remineralising blends available; one recommended for use with amphibians is:

Recipe for Reconstitution of RO Water
(from Kevin Zippel: http://home.att.net/~kczippel/waterqual.html)

Per 100 gallons (455 litres) RO water:

15.0 g $CaCl_2$ (calcium chloride)
17.6 g $MgSO_4 \cdot 7H_2O$ (magnesium sulphate)
13.6 g $KHCO_3$ (potassium bicarbonate)
11.3 g $NaHCO_3$ (sodium bicarbonate)

0.5 g commercial trace element mix*

Dissolve all crystals in a jar of RO water and add to RO water storage vat. Blend thoroughly before use.

* Available through hydroponic gardening suppliers (e.g. #6 Chelate Trace Element from Homegrown Hydroponics in the U.S.A.)

Final composition (similar to moderately soft fresh river water):

General Hardness: 3 degrees
Carbonate Hardness: 2 degrees Ca:Mg (3:1)
Na:Ca+Mg+K (1:4)
pH ~ 7.4 (depending on aeration)

HEATING WATER

- Always use water from a cold water tap and either allow it to reach room temperature prior to use, or heat it to the required temperature; **never** use water out of a hot water tap. Hot water heaters can contain impurities, and hot water dissolves metals, especially lead, much faster than cold water if passing through metal water pipes, and may also leach toxic vinyl chlorides from plastic water pipes – PVC pipes in particular should only be used with cold water.

FILTRATION AND WATER FLOW

General considerations

- Good water quality in an aquarium is dependent on efficient filtration of the water.
- Where possible, use living matter to bind excess nutrients rather than relying on artificial filtration.
- It is a very good idea to have regular, scheduled maintenance regimes, and a log for each aquarium that all maintenance procedures, problems, etc. are recorded on.
- There are three types of filtration: mechanical, chemical, and biological. In general, the sequence is mechanical → biological → chemical.
- A very basic, but very important, point – always ensure the filters are plumbed in properly!
- If the filtration system has an intake siphon, a noncorrosive guard will need to be made to prevent smaller animals from entering this.

Water turnover & water pumps

- Filters can be powered by air, rotary impeller motors, or water pumps. Systems that use water pumps can be divided into three types: open, closed, and re-circulating.

-- Open systems make use of gravity, using an overflow / siphon box in or attached to the aquarium to return water to a source reservoir located below the aquarium (the filtration system is located in this reservoir), and then a

pump to send water from the source reservoir back up to the aquarium (*e.g* sump system; refer to Sumps below for more information).
-- In closed systems, the water is forced through closed filter canisters or modules (*e.g.* the entire system is sealed except for the pump intake and the return line leading back to the aquarium or reservoir, both of which are attached to the one body of water).
-- In re-circulating systems, the water is drawn from and returned to the same open aquarium or reservoir, either to increase the water current or to drive a submersible filter (*e.g.* under gravel filters). Small submersible pumps or power heads are usually used for simple re-circulating systems.
- If two or more return lines are being used to return water from an external filtration system to the aquarium, a more powerful pump will be required, as water flow decreases through multiple returns. Including a valve / tap on each return line allows control over the rate of flow out of each return line.
- When a pump returns water to an aquarium, every bend in the return line creates resistance, and in-line filter material (*e.g.* canister filter or micron module) also offers resistance. The greater the resistance, the more backpressure the pump must operate under, and the more powerful the pump must be.
- The bigger the pump, the more heat it will produce. Air-cooled pumps tend to run cooler, but generate more noise, whereas water-cooled pumps are quieter, but produce more heat. Submersible pumps are also quiet, but transfer heat efficiently because they are submersed in the water.
- When setting up an aquarium, an important consideration is the rate of water turnover (*i.e.* the number of times the volume of water in the aquarium passes through the filter per hour); the ideal rate of water turnover for a given system will depend on the stocking density, amount of excess food, etc. Closed systems usually call for a higher rate of water turnover than open systems, and typically require more powerful pumps that generate more pressure (*e.g.* pressure or high-head pumps). While there seems to be considerable debate on the topic, a general guide is to use a pump / filter that will turn the aquarium volume over three times per hour in open systems and four to six times per hour (more frequently the greater the bioload) in closed systems (so the flow rate of the pump / filter must be appropriate to produce the desired rate of water turnover). If the aquarium requires more current, small power heads or submersible pumps may be used to increase water flow.
- In addition to flow rate, head pressure is also used to describe how powerful a pump is. "Head" can be defined as any resistance to the flow of a pump. When pump manufacturers state the head pressure, they are referring to the vertical discharge pressure head, which is the vertical lift in height at which a pump can no longer exert enough pressure to move water (at which point, the pump has reached its "shut-off" head pressure). The higher a pump's head pressure, the more powerful the pump.
- To use flow rate and head pressure to select a water pump, you first need to know: (1) how much water will move through the filter system (*i.e.* total volume of the aquarium and filters), (2) the required rate of water turnover (to calculate required flow rate, multiply the number of times the water in a system should be turned over per hour by the total system volume), and (3) how much resistance (head) the pump will encounter as it moves water through the system. While the first two are simple, calculating the resistance a

pump will encounter when running is more complicated; refer to Aquariumpros.com, 2005 for (over-simplified but still useful) calculations.

Mechanical filtration

- Mechanical filtration removes solid particles from the water (*i.e.* removes free-floating wastes before it decays); as these waste particles are concentrated in the filter medium, rather than physically removed from the system by it, they will still decay while trapped in the filter. This means that mechanical filter media must be replaced / rinsed clean every few days – four weeks (depending on the aquarium set-up and its inhabitants) to be beneficial.
- Mechanical filter media include filter floss, sponges, paper cartridges, aquarium sand, and diatomaceous earth. Floss is inexpensive and has openings of different sizes, and so does not clog as quickly as paper or sponges. Diatomaceous earth can trap extremely fine particles (down to one micron) but is expensive and requires the most maintenance (because diatom filters are so thorough, they require frequent cleaning; once they become clogged, the water flow will be restricted to the point where turbidity in the aquarium actually increases); diatom filters may be best used regularly, rather than continuously, or as required to tackle particulate matter problems, stubborn algae, or to 'polish' water (*i.e.* clean water very quickly).
- Nitrifying bacteria (see 'Biological filtration', below) will settle on the mechanical filter media; partial media changes are therefore preferable (if possible – filter floss can be partially changed).
- Mechanical filtration will not remove particles that have settled onto the substrate – a siphon / gravel 'vacuum' is still required to remove these.

Biological filtration

- Proper management of the nitrogen cycle is critically important in aquaria; biological filtration is the process by which the highly toxic ammonia produced by aquatic animals and the decay of proteins is converted initially to slightly less toxic nitrites and ultimately to much less toxic nitrates through the cultivation of nitrifying bacteria in the aquarium system.
- Nitrifying bacteria will colonize all of the surfaces available inside the aquarium, so the biological filter is simply a place in the filtration system where there is a very large surface area available for these bacteria, and the efficiency of a biological filter relies on the total surface area available. Some biological filter media are more efficient (*i.e.* have a greater total surface area for a given volume of media) than others, so it is important to choose the medium carefully.
- Biological filter media should be chemically inert, and include sponges (a sponge may be sufficient for small aquaria, and is often the best choice for breeding or hatchling tanks, as they do not pose a danger to hatchlings that could get sucked into larger filters) as well as dedicated plastic bioballs, ceramic biomedia, biowheels, etc. Hortag (or similar horticultural clay balls) can also be used as the substrate for biological filtration, as they are inexpensive and have a reasonably large surface area.
- Biological filtration works most efficiently at approximately 30°C and pH = 7.5.

- It is very important that water passes through the mechanical filter ***before*** passing through the biological filtration media, because the bacteria that break down organic debris multiply much faster than nitrifying bacteria, and will consume the oxygen that the nitrifying bacteria require (the rate at which nitrifying bacteria can process ammonia and nitrite is limited by the amount of oxygen available in the water).

Cycling / maturing biological filters

- A biological filter will not establish and mature without a source of ammonia; however, high levels of ammonia are actually toxic to the nitrite-oxidising bacteria, so their colonies cannot develop until after the ammonia level has peaked.
- There are several options for cycling a biological filter: (1) naturally, using hardy aquatic animals (*i.e.* ones that can tolerate ammonia and nitrite) to produce the ammonia required to kick start filter maturation, (2) using ammonium chloride, and (3) using a product such as ABIL (Ammonia Binding Inoculum Liquid), which contains a concentrated live culture of nitrifying bacteria.
- Naturally cycling biological filters takes a considerable amount of time (and the cooler the water temperature, the longer it will take – up to 10 weeks in low temperature systems), which can be a problem when setting up aquaria for amphibian spawn / larvae as you do not necessarily know when eggs will be laid, so may not have enough advance notice to mature filters using this method (particularly for species that do not require a rain chamber to breed). Also, there are obvious and very serious biosecurity issues associated with using hardy fish, amphibian, or invertebrate species to establish the filter and then swapping them for the target species.
- Ammonium chloride can be used to mature filters more quickly (10-14 days for tropical aquaria, up to 30+ for temperate aquaria), but once the filter is mature it is very difficult to hold it at a steady state for any more than a few days without animals in the system (this is because ammonia is toxic to *Nitrobacter*, so it is difficult to feed the first stage bacteria without killing the second stage bacteria). This means that animals need to be added to the system virtually as soon as the filter is mature, this can again be a problem when preparing aquaria for amphibian spawn / larvae as it often is not possible to predict to within a few days when a particular species will produce fertile eggs. Also, this method of filter maturation only has a 70-80% success rate, as some aquaria just do not cycle completely / at all.
- As ABIL (~£60/l from Avecom Aquaculture Products, 1l will dose 2500l water) is a concentrated culture of nitrifying bacteria that directly detoxify ammonia, it can be used to mature a tropical aquarium filter in three days (note that it can also be used to reduce the number of water changes required, and to boost biological filters following the use of anti-bacterial treatments in the tank). This product should be dosed directly into biological filters (switching off any mechanical or chemical filters first, and leaving them off for 72 hours following dosing), although it can be added to the water. In new, sterile systems that do not have any ammonia or nitrite in the water, it should be used in conjunction with ABIL Mineral Nutrient (prior to adding any aquatic organisms). The success rate using ABIL is 90%. → *One consideration is the source of the innoculates and culture solutions – where*

do these originate from? Is there a biosecurity issue, or do they use a sterile culture?
→ ***Recommendation***: If suitable (*i.e.* depending on the source of the cultures), use ABIL to mature filters in aquaria that are set up quickly in response to unpredictable breeding events.

Chemical filtration

- For chemical filtration media to work effectively, water should be mechanically filtered ***before*** passing through the chemical filter, and there should be a good flow of water through the filter.
- **Activated carbon** is the most commonly used form of chemical filtration. It can be used to remove organic compounds including pollutants, acids, proteins, hormones, antibiotic compounds, a variety of chemicals, medications, metals, and minerals, and inorganic substances such as chlorine / chloramines and phenols. Substances adsorbed by the carbon will remain biologically active, and waste particles trapped in the carbon will still decay; ***activated carbon therefore needs to be placed after mechanical filtration in the filter sequence (as noted above), and be replaced regularly***. It is also important to note that if activated carbon is left in the system too long, it will begin to function as a substrate for nitrifying bacteria (*i.e.* as part of the biological filter), so it's subsequent removal will reduce the capacity for biological filtration.
--- Activated carbon will not adsorb substances such as ammonia, nitrite, nitrate, phosphate, or inorganic salts.
--- Activated carbon works in three ways. The first is adsorption (as opposed to absorption): static forces attract particles, adsorbing them onto the surface of the carbon; bacteria that settle on the surface of the activated carbon further consume the waste. The second is the diffusion of gases; they are absorbed by the activated carbon and detoxified (*e.g.* ozone, O_3 into oxygen, O_2). The third is chemosorption; particles are irreversibly bound to the activated carbon.
--- The effectiveness of a particular activated carbon for aquarium water purification depends on several factors, including surface area, pore size distribution, pore volume, and particle size. Carbons with a higher surface area will obviously hold more impurities; it is important to note that virtually all the useful surface area in activated carbon is along the interior pores rather than the outer surface of each piece, which actually has a negligible surface area in terms of adsorption because it is not porous. The surface area is clearly related to the pore size distribution, and carbons with extremely high surface areas (*e.g.* > 900 sqm / gm) are actually not ideal for use in aquaria, as most of the pores are micropores, and are too small for the larger molecule organic pollutants present in aquarium water. Carbon has a high pore volume when it has a relatively high proportion of medium and large pores and a large surface area; a good pore volume for aquarium filtration is approximately 1.0 to 1.5 ml / gm (Greenfield 2000). Particle size should be about pin-head, as large particles cannot be completely penetrated by water and so only the outer 1-2 mm of the particles are adsorbent (Hallman, 1995).
--- In terms of porosity suitable for aquarium filtration, coal-based carbons are best, followed by wood-based; coconut shell-based carbons are least suitable

(this is because coconut carbons have only very small pores, or micropores, and much of the organic pollutants in the water are larger than the pores).
--- Another important characteristic of activated carbon is its ash content (ash is a residue of carbonisation and activation). In terms of ash and phosphate content, acid washed carbons are preferable to non-washed carbons, as acid washed carbons have had most of the ash and phosphate washed out (ash is responsible for "pH shock"; the high ash content of some carbons can rapidly increase pH to over 10, whereas acid washed carbons may only increase pH to approximately 7 over several days). Carbons that do not affect pH generally do not leach much phosphate (Hallman, 1995).
--- The amount of activated carbon that should be used varies from one aquarium to another; between three tablespoons and one cup per 250l water is generally recommended.
--- Adsorption usually increases as pH and temperature decrease.
--- As activated carbon adsorbs particles, it will exhaust, and therefore needs to be replaced regularly. An indicator of exhausted carbon is a yellowish tint to the water. The frequency of replacement is in large part dependent on each individual aquarium volume and setup; replacement may be required as infrequently as every six weeks to as often as every 12 hours.
--- If using it to remove medications, it should only be used for a couple of days before being removed and discarded.
--- Once the carbon is exhausted a release of the adsorbed particles back into the water is minimal under 'normal' aquarium conditions; for most substances adsorbed by activated carbon, this will only occur under specific conditions (*e.g.* extreme pH values). (Note that a number of fish-keeping websites and other sources state that activated carbon filters will re-release the adsorbed contents in large doses if they are allowed to become saturated, however this is just a wide-spread myth; adsorption is based on chemical bonding, and these bonds will not break unless chemical parameters are changed.)
--- Another common myth is that, if the carbon has been washed with phosphoric acid, phosphorus will leach into the water from the carbon; acid-washed carbons are actually preferable because they contain less, not more, leachables such as phosphate (refer to point about ash content, above).
--- When using activated carbon, keep in mind that: (1) oxygen depletion can result from the use of too much carbon, particularly when new (this can be avoided by pre-soaking the carbon for half an hour to an hour before placing it in the aquarium filter), (2) activated carbon readily absorbs most aquarium medications, especially antibiotics, so must be removed during treatment periods, and (3) using activated carbon in planted tanks might deplete some trace elements needed for plant growth (if they are chelated); in this case, activated carbon can be used only one week per month, or non-chelated mineral supplements can be used in conjunction with the activated carbon.
- **Other adsorption media** used in chemical filtration include phosphate removal media (*e.g.* PhosBan, a synthetic ferric oxide hydroxide) and synthetic polymers that target nitrogenous organic waste (*e.g.* Purigen).
- **Ion exchange resins** are also used for chemical filtration; they are synthetic polymers containing positively or negatively charged sites that can interact with or bind to an ion of the opposite charge from a surrounding solution (*e.g.* heavy metals including iron and copper, calcium and magnesium (to soften hard water), and ammonia, nitrite, and nitrate). They are light, porous solids

that are typically in the form of beads or membranes, and, once saturated, can usually (depending on the medium) be recharged using salt or carbonate solutions, although they will lose their capacity over time. Zeolites are minerals that have ion-exchange properties, and they are commonly used to remove ammonia from water.
--- A high dissolved organic content in the water will significantly reduce the effectiveness of these resins, so water should flow through activated carbon first, then through the resin.
--- Temperature and pH affect the efficiency of ion exchange.
---The water flow rate is also a significant factor; most resins will not work effectively if the flow rate is too high.
--- If ammonia is targeted, it is imperative that it is monitored closely during the fitration process, because, when the resin is saturated, ammonia levels can quickly rise to dangerous levels.
--- Deionising (DI) units consist of two resins, one anionic and one cationic.

Sponge filters

- A good quality sponge filter used alone will provide adequate filtration in a small aquarium with a low bioload. However, it would be insufficient in even a 20l aquarium with a high bioload (particularly when the feeding rate is high).
- Sponge filters may be particularly useful in aquaria containing hatchlings / early stage larvae, as they are not drawn into the outflow, the water circulation is so gentle that larvae do not become trapped, and even small tadpoles can graze on the surface of the sponge without problem.
- One problem that may occur when using sponge filters in systems with tadpoles is an inadequate rate of water turnover – in systems where animal density and feeding levels are high (which is the case in most tadpole tanks), the water turnover should be at least four times / hour in order to keep up with the amount of waste being produced, so if the water is not turning over frequently enough, ammonia and nitrite will be present in the system, and there may be problems with heterotrophic bacteria.
- Dead spots (which allow heterotrophic bacteria to flourish and deoxygenate the water) often occur when using sponge filters, so it is a very good idea to use an airline in conjunction with a sponge filter in order to avoid this.
- Sponge filters have reasonable 'survivability' (in terms of nitrifying bacterial communities) when the power is shut off, as they are physically in the aquarium.

Box filters

- Box, or corner filters, use air to create water flow through the layered filter media (usually mechanical, biological, and chemical); the flow rate can be adjusted by altering the air flow.
- They are inexpensive and easy to clean, but only work well in small aquaria with relatively low bioloads.

Undergravel filters

- Undergravel filters work by passing water slowly through gravel that is sitting on a perforated plate on the bottom of the aquarium. The water can be pumped with an air lift (a vertical tube is attached to the perforated plate, and

an air stone in the tube creates air bubbles that 'lift' water through the tube). A submersible pump can be attached to the lift tube to increase water flow.
- Undergravel filters are cheap, and they are very effective biological filters (the slow flow of water through the gravel facilitates large colonies of nitrifying bacteria). Unfortunately, though, they are very poor mechanical filters, as wastes are pulled down into the gravel, which clogs up with decaying organic matter. Regularly vacuuming the substrate and frequently carrying out partial water changes are therefore essential when using an undergravel filter.
– Reverse-flow undergravel filtration is a partial solution to this problem; water is mechanically filtered first, by either a canister filter or a sponge / foam block, then forced *down* through the undergravel filter tube into the space below the perforated plate so that it percolates *up* through the gravel. This is only a partial solution because waste still accumulates in the gravel, and it can be difficult to achieve even water flow throughout the gravel bed.
- If an undergravel filter is being used in an aquarium, it cannot simply be turned off if it is no longer required, it must be completely removed, as there is likely to be a considerable amount of organic matter in the gravel and under the plates. This organic matter will degrade aerobically when the filter is working, but once the water flow stops and anaerobic conditions prevail, the products of decomposition will be considerably more toxic.

Power filters

- Power filters commonly hang on the back or side of an aquarium, and consist of a siphon tube that pulls water from the aquarium into the filter box (which contains the filter media), and an internal pump that returns the filtered water to the aquarium. Some also have a wet-dry wheel, or biowheel, positioned after the filter box; water coming out of the filter box is directed over the wheel, rotating it, which increases oxygenation and thus facilitates a large colony of nitrifying bacteria. One drawback of these wheels is that they can jam, so they must be checked regularly.

Canister filters (*e.g.* Eheims)

- These filters are usually external to the aquarium, sitting on the floor below it, but they can also hang on the side of the aquarium or even sit inside it (in which case they are referred to as submersible filters).
- Canister filters are designed to provide more powerful mechanical filtration, so they are particularly beneficial in aquaria with large animals or messy eaters that generate a lot of waste.
- For these filters to work effectively, they must be cleaned frequently to prevent the decomposition of waste that accumulates in the filter media and is then exposed to the water flowing through the filter. *(Refer to "Filter maintenance" below for recommendations on cleaning filters.)*
- A second layer of filter wool can be added if activated carbon is not being used in the filter.
- Nitrogen gas problems can result when airlines, sponge filter outlets, etc., are placed next to the intake for an external filter, as a low pressure zone may be created, which will cause the water to become supersaturated with nitrogen gas. The water then degases in the aquarium, and the animals essentially get the bends. → If an airline or sponge filter outlet is accidentally

placed near the external filter intake, the filter will often either airlock or there will be a fine mist of bubbles (Venturi effect) from the filter return.
- A general rule with external filters is that the nitrifying bacteria will start dying within an hour of the power being shut off, as oxygen levels drop quickly due to heterotrophic bacteria. If a power cut occurs or the filter is accidentally switched off, even just briefly, run the filter to waste for several minutes in order to flush out any dead / dying bacteria (also, the water in the filter will have virtually no oxygen left in it).

Fluidized bed filters / reactors

- Fluidized bed filters (also referred to as suspended particulate filters) are supplemental filters that can be very useful in large, heavily stocked aquaria as they greatly increase the efficiency of biological filtration. By "fluidizing" or suspending fine grained media in a column of water, the surface area available for bio-filtering and the contact time are greatly increased, so fluidized bed filters can be quite a lot smaller than other types of filters that can cope with the same bio-load (fluidized bed reactors work on the same principle, but employ chemical media for more efficient chemical filtration).
- The filter is a water-filled cylinder that hangs off the back of the aquarium and is connected to a water pump in the aquarium (*e.g.* a power head). The pump forces water into the bottom of the filter and up through a churning mass of fine grained media such as sand, silica chips, or plastic chips, and then flows back into the aquarium from the top of the filter. Because of the speed at which water is passed through the filter media, it becomes fluidized (*i.e.* it is constantly being pushed up by the current and then falling back through the water in response to gravity).
- Fluidized bed filters are easy to maintain, and they are ideal for use with planted aquaria, as they do not drive off CO_2. Other advantages of these filters are that once the bacterial bed is established, it does not have to be disturbed when performing routine maintenance, as is the case with other filtration systems; they do not clog during use, as any particles that enter the filter ultimately pass through (*i.e.* they do not function as a mechanical filter at all); and because water is evenly distributed as it flows through the cylinder, pockets of anaerobic bacteria do not develop.
- A word of caution: if the water pump stops because of either a power cut or mechanical failure, the sand will settle to the bottom and become anaerobic (potentially quite quickly), causing the death of the aerobic nitrifying bacteria. Anaerobic sand may also release highly toxic hydrogen sulphide, and this can happen within hours of pump failure. A backup generator, or even a battery-operated air pump, can be used to prevent the filter dying in a power outage, as it will keep the sand moving around and oxygenated enough to prevent problems from developing, at least temporarily.
- Fluidized bed filters do deplete the water of oxygen, and the amount of oxygen in the filter is limited to the amount carried in with the water (*i.e.* the water is not oxygenated inside the filter), therefore the water entering the filter needs to be well oxygenated to ensure efficient filtration.

Trickle filters (also called trickle towers, bio-towers, or de-gas towers)

- **Problem:** With large filtration systems, dirty filters, or in any system where there is a high bio-load and closed filtration (and therefore less chance for the water to de-gas), carbon dioxide can build up as a result of bacterial respiration (and this effect is exacerbated by heterotrophic bacteria), causing both oxygen and pH to drop → **Solution**: Trickle filters are very good for restoring gas equilibrium in systems (and hence will also act to increase the pH if it was being suppressed); they should be placed at the end of the filtration sequence (*i.e.* general filter, UV filter*, then trickle filter). * The UV filter should be placed before the general filter if the primary function of the UV filter is to kill algae.
- As a general rule, trickle filters should be over-sized by up to 10 times (in terms of the amount of media in the filter, note that each different type / brand of media will have its own SA/m^3); this is to increase the ability of the filter to restore gas balance.
- The name says it all: *trickle* filters; water loses pressure as it passes through a trickle filter, so, unless the trickle filter is placed above the aquarium, you cannot have pressurized return to the aquarium without using a pump.
- Trickle filters can also be used as the primary biological filter.
- A layer of filter wool / matting placed on top of the trickle filter will function in mechanical filtration and may be all that is required for the system; however, if it is insufficient to prevent the trickle filter filling up with organic material, then additional mechanical filtration is required (otherwise the bacterial community in the trickle filter will shift from nitrifying to heterotrophic). Also, it is essential that the filter matting on top of the trickle filter is kept clean (see next point).
- Care needs to be taken to avoid channelling water down the sides of the trickle filter – there should be a distribution network of spray nozzles at the top of the filter to distribute incoming water (ideally), and a spreader plate with holes drilled in it under the filter matting to distribute water evenly through the filter media (required), and the filter matting must be kept clean as dirty matting can cause water to channel down the sides rather than through the media.
- Trickle filters can be used with virtually any size aquarium, as even very small ones can be constructed from plastic boxes or buckets (note that they do not need to be cylindrical) – sit the trickle filter on top of the aquarium, and direct the external filter return through it.
- Trickle filters have much better 'survivability' than external filters when the power is shut off – the filters can be maintained during power outages by pouring a bucket of water over them every half hour.
- One disadvantage of trickle filters is that they are physically large (in order to function effectively in bio-filtration and gas exchange, they require a volume that is a significant fraction of the aquarium volume).

Sumps

- A sump is really just an additional container of water that sits outside your aquarium and houses the filters, etc.; it is positioned below the waterline in the aquarium, and uses a siphon overflow system to move water out of the aquarium into the sump, and a pump to return water back up to the aquarium following filtration. Ready-made sumps that are divided into chambers for

various filtration methods, equipment or a refugium can be purchased, or DIY sumps can be constructed from old aquaria or other suitable containers.
- A sump can be any size, but is usually smaller than the aquarium it is attached to.
- A major advantage of a sump is that it increases the total volume of water in a system (*e.g.* if an aquarium is 200 litres and the sump is 80 litres, then the total volume of water for the system is 280 litres). The larger the volume of water in a system, the more stable the water chemistry and temperature will be (and the less stressful it will be for the inhabitants). Other advantages of a sump include: it can be used to house a large volume of media for biological filtration; partial water changes can be carried out in the sump, and medications, etc. can be added into the sump, which means that the 'new' water / medications / chemicals are well mixed with the aquarium water before entering the aquarium; increased water circulation, which can be further enhanced by using multiple return outlets aimed in different directions; increased oxygenation; algae or other plants can be grown in the sump to take up excess nitrates; the water level in the aquarium will remain constant, as evaporation will only affect the water level in the sump (and an automatic top-up device can be used to keep the sump filled up from an associated water holding tank).
- A very basic, but important, point to remember when setting up a sump is that water needs to be pumped out of the sump at the same rate that it enters it! Also, to avoid the possibility of a sump overflowing, it must have room for excess water. When a sump is running, as water drains into it from the aquarium, it is pumped back up to the aquarium; when the pump is off, water from the drain line, return line, and the aquarium (the volume of which is determined by the depth of the weir / overflow inside the aquarium and the depth of the return line in the aquarium) will drain into the sump. Siphon breaks (*e.g.* two 3mm holes) should be drilled into the return line, approximately 1cm below the water's surface when the aquarium and sump are running normally. This is so that, when the pump is off and water is being sucked out of the aquarium through the return line, air will be sucked in through these holes as soon as the water level reaches them, and this will break the siphon.
- An integral part of a sump is the overflow, which drains water into the sump from the aquarium. The overflow is either inside the aquarium or hangs on the back or side of the aquarium (in a fixed position) so that water that rises above that level in the aquarium overflows through the drain into the sump.
- Sumps are more commonly used in marine systems than freshwater, however many of the advantages of sumps also apply to freshwater systems, and they may be particularly useful in certain situations:

    -- aquaria with high bioloads (*i.e.* high stocking densities, predatory species, messy feeders, etc.), or

    -- to centralise the filtration for multiple aquaria {*e.g.* two aquaria set up adjacent to one another that share a common sump; in these set-ups, it is important to ensure that, in each aquarium, the overflow can handle the return (and not just that water is pumped out of the sump at the same rate it enters the sump; this is particularly important to take into consideration when the aquaria are different sizes, otherwise substantial flooding of the smaller aquaria may occur), and the sump should be over-sized in order to handle the overflow of both aquaria if the power is off; the drawback of having more than one aquarium running off a sump is that, if something goes wrong with the system, both aquaria are affected}.

- A sump may not be the best option for planted aquaria that have CO_2 pumped into them, as the CO_2 dissipates as the water flows down into the sump (CO_2 can be injected directly into the aquarium, or into the return line from the sump to the aquarium, but considerably greater quantities of CO_2 will be used in a system with a sump than in one without).
- Filtration sumps can be configured in a multitude of ways, especially multi-chambered sumps; common configurations are Berlin filters (salt-water aquaria only), algal filters (used in salt-water aquaria to remove nitrates from the water), and bio-media filters (freshwater aquaria). Sumps can also be used as trickle filters.

UV filters

- UV filters are good for killing fungi, bacteria (they are a very good way of controlling excess bacteria) and algae, but are less effective with protozoans. ZSL found that using a UV filter for a week clears wild-caught river shrimp of *Aeromonas* and *Pseudomonas* infections (A. Sharp, pers. comm.).
- The UV filter should be placed after the general filter so that the water is 'clean' when it enters the UV filter (unless you are using a UV filter to control algae, in which case it should be placed *before* the mechanical filter, so that dead algae are then removed by the mechanical filter).
- There is an argument that UV filtration is a crude selective force on bacteria (*i.e.* selecting those that can withstand UV) – this could be a problem if UV fliters are used in breed-for-release and hold-for-translocation conservation programmes, as you could then be releasing animals with skewed bacterial communities or loads, or with 'superbacteria'.
- Lamps need to be changed every six months.

Filter maintenance

- Regular cleaning of filters is incredibly important as debris will build up and inhibit the flow of water through the filter media (the flow rate through the filter is very important – an anaerobic filter environment, resulting from slow flowing or stagnant water, actually produces toxic substances such as ammonia and hydrogen sulphide); in biological filters, the bacterial community present can shift from nitrifying to heterotrophic if the filter is dirty (as the bacteria feed on all the organic matter in the filter rather than the ammonia).
- ***External filters should be cleaned AT LEAST every two weeks (and preferably weekly) if there is a medium to heavy bioload and / or lots of particulate matter*** (as is almost always the case in tadpole aquaria), as the filter wool will get dirty very quickly and the filter will end up dominated by heterotrophic bacteria. In systems where the bioload is very low, it may be possible to leave it up to six weeks (but it should still be checked weekly).
- ***Always clean biological filtration media in the aquarium water***, using any other water will kill the nitrifying bacteria.
- When cleaning Eheim filters, check the impellor to make sure it does not have any filter wool wrapped around it (it can cause a blockage, and the pump will then burn out).

- Clean all tubing and pipes as necessary; flow can be reduced by up to 90% if the supply lines are blocked with algae – if they block and the water flow is reduced, not only does the filter not work efficiently, but the water is proportionately deoxygenated much more, and the nitrifying bacteria may die off.

Recommended filtration systems for amphibian aquaria

	Aquarium volume (l)					
	10		50		200	
	Low bioload	High bioload	Low bioload	High bioload	Low bioload	High bioload
Filtration	sponge filter	sponge filter + airline	external canister filter (two sponge filters may be sufficient)	external canister filter + airline (trickle filter even better)	external canister filter + airline (trickle filter even better)	external canister filter + trickle filter OR sump
Water changes	10 – 20% once per week	10 – 20% three times per week	10 – 20% three times per week	10 – 20% three times per week	10 – 20% three times per week	10 – 20% three times per week

- In a 20l aquarium with a high bioload, a small external filter and a homemade trickle filter with microjet would be ideal.
- When large numbers of amphibians are kept in small volumes of water, it may be necessary to use a flow-through system.

REGULAR PARTIAL WATER CHANGES

- As mentioned above, nitrate is the end product of the aerobic process of nitrification, and usually accumulates in closed aquatic systems; as well as direct lethal and sublethal effects on aquatic animals, nitrate can also adversely affect aquatic species by altering the alkalinity and pH of a system. Regular partial water changes are thus necessary to keep nitrate levels as low as possible, and to maintain high water quality in general.
- As a general rule in freshwater systems, approximately 25% of the volume of water should be changed per week (although it depends on the number and size of animals, the volume of water, frequency of feeding, efficiency of the filters, presence of plants, occurrence of treatments, etc. in a system; in particular, quarantine aquaria or systems with high stocking densities may require a greater percentage of the total volume to be changed per week).
- The larger the volume of water removed from a system and replaced at one time, the greater the change in water chemistry (and therefore the more stressful it is) for the inhabitants of the system; thus it is preferable to ***change smaller volumes more frequently*** (*i.e.* 10% two - three times per week instead of 25 – 30% once a week, unless stocking density is very low). ***However, if dealing with quarantine animals, the number of 'incursions' into the aquarium should be minimised in order to reduce the chances of lapses in biosecurity.***

- The 'new' water added to a system should be the same temperature, pH, GH & KH as that in which the animals are living, should be well oxygenated, and chlorine- & chloramine- free.
- To determine how much water to remove how often, changes in relevant water chemistry parameters between and immediately before and after water changes should be monitored, and the volume / frequency of water changes adjusted to see how these adjustments affect changes in water quality.
- No more than 30% of the volume of water should ever be changed at once, unless there are acute water quality problems (in which case 40-50% can be changed at once, although it is still preferable to change 25-30% several times in succession, *e.g.* daily or at intervals throughout the day).
- In systems with low pH and low alkalinity that are being dosed with carbon dioxide (*e.g.* Amazon systems), more frequent water changes may be required to keep the alkalinity low, but this will depend on stocking density and feeding levels (if either is / both are high, then nitrification will counteract the increasing alkalinity, as nitrate 'eats' alkalinity) and on the type of rock present in the system (as low pH will be dissolving rock), if any.

IDENTIFYING WATER QUALITY PROBLEMS IN AQUARIA

Monitoring water quality - why

- Regular measurement of critical water quality parameters is essential to assess the performance of filtration systems and to minimize health risks to aquatic animals → ***If you don't measure it, you can't manage it!***
- As well identifying one-off problems, regular testing also allows the detection of recurring problems, and facilitates the assessment of any corrective measures.

Monitoring water quality - what

- For each aquarium, a water quality log should be maintained by keepers to track changes in water chemistry over time, and identify potentially harmful trends before they cause problems. Parameters to test in freshwater systems include:
    - Temperature (this is very important, and ***must*** be recorded when any other water parameters are measured!!)
    - pH (use a probe, as chemical test kits are very poor indicators; be aware that pH will fluctuate over the course of 24 hours due to algal / plant photosynthesis – respiration cycles)
    - GH
    - KH
    - ammonia
    - nitrite
    - nitrate
    - phosphate
    - oxygen (use a probe, as chemical test kits are very poor indicators)
    - if you are worried about an ion imbalance in the system, also test for sulphate and iron
    - if you have live plants in the system, also test for potassium, magnesium, sulphate and iron

Monitoring water quality - how

- As a general rule, pet shop chemical test kits are inadequate for testing water quality parameters (they are often imprecise and / or inaccurate, and are not very sensitive, so should really only be used for presence / absence; also, the waste test water from kits for some parameters, *e.g.* ammonia and nitrate, is toxic).
- Any test that relies on serial dilutions will not provide accurate results unless nanopure water is used as the blank (hence ZSL's Aquarium uses pet.shop test kits for nitrate, despite the fact they are quite imprecise and inaccurate, as the RO water they use as a blank in the spectrophotometer still has traces of nitrate left in it, which means the result can be out by a factor of four).
- If pet shop test kits are to be used to test any water chemistry parameters, Salifert are the best choice (recommended by A. Sharp).
- Spectrophotometry will provide more precise and accurate test results (A. Sharp, pers. comm.).
- Test vials should be rinsed with RO water rather than tap water, as tap water will contaminate samples & influence results.
- Water temperature, pH, ammonia, and nitrite should be tested daily for at least a week after an aquaria has been stocked for the first time (or after substantial changes to the stocking density) to ensure that conditions are appropriate.
- After this, each aquarium / system should be tested for all 'relevant' parameters once / week (if the stocking density is low and the water chemistry is quite stable, then it should be possible to reduce the frequency of testing to once / fortnight, although ***tadpole aquaria should always be tested weekly due to the high degree of flux in these systems*** resulting from tadpole growth, changing feeding rates, decreasing numbers of individuals as they begin to metamorphose, etc.). Note, however, that it may be necessary to test alkalinity (KH) up to four times / week in tropical systems (once / week is usually fine in temperate systems).
- ORP (oxidation-reduction potential) monitors are not necessary in freshwater systems (the exceptions are when ozone is being used, or when there is concern that the water may be very dirty, but even then biological oxygen demand (BOD) can be measured instead).

RECTIFYING WATER QUALITY PROBLEMS IN AQUARIA

When test results indicate a problem...

- If trends in one or more parameters become apparent, questions to ask include:
    - Are water changes occurring frequently enough?
    - Is appropriate water being used for the water changes?
    - Are all necessary filters (including RO filters) installed and functioning correctly?
- If positive results are obtained for ammonia or nitrite, test the water at different times (*e.g.* before and after feeding, before and after water changes, etc.).

Adjusting pH

- pH changes need to be gradual – no more than 0.1 / 10 mins (and ideally not more than 0.3 / 24 hours).
- If the pH in an aquarium drops more than approximately 0.2 over a month, it may be necessary to either increase the KH or perform partial water changes more frequently.
- To provide water with a low pH, there are several options: (1) use carbon dioxide units to add carbonic acid, (2) add any type of organic acid to the system (*e.g.* leaves such as almond, oak, etc.; peat or sphagnum moss tied up in a piece of cloth or hosiery, although I could not find any evidence that this has been tested properly), or (3) reverse-osmosis filtered water reconstituted to the appropriate pH and alkalinity. Note that the blackwater extract sold in pet stores is largely useless (it will not hold the pH down for even 24 hours in water with a 'resistant' buffering system); however, it may be worth experimenting with blackwater extract and your aquarium water to determine whether you could use it as an emergency measure if a situation arises where it is necessary to decrease the pH as quickly as possible (given the constraint of the first point in this section!).
    - Carbon dioxide dosing systems allow precise control, but they simply suppress the pH (as opposed to physically altering the nature of the buffering system), so CO_2 must be added constantly to keep the pH low, and a large volume of CO_2 will be required in systems that are heavily aerated, as the water constantly degases. Surface turbulence should be minimized as much as possible in aquaria with CO2 units, as it increases the rate at which the CO_2 degases (and the pH rises). It should also be noted that water with a 'resistant' buffering system will require large amounts of CO_2 to suppress the pH, and CO_2 units are really only useful in re-circulating systems.
    - RO water reconstituted to provide an appropriate pH and alkalinity is the best option, particularly for smaller systems and flow-through aquaria.
- To increase pH, increase the buffering capacity of the water (refer below).

Adjusting buffering systems

- To increase alkalinity / stabilise pH, add either sodium carbonate or sodium bi-carbonate (the excess Na^+ will not be a problem in flow-through systems or systems where frequent partial water changes are occurring, or if the sodium carbonate / bicarbonate is only being used as a short-term fix), or filter the water through calcium carbonate.
- In marine systems, if the pH is less than 8.2, it is better to add sodium carbonate than sodium bi-carbonate (sodium bi-carbonate is better than nothing, but if may cause the pH to drop initially and then rise again), but this may not apply to freshwater systems.
- To increase alkalinity with sodium bi-carbonate (baking soda) add a small amount to the system (approximately 1/8 teaspoon per 75l of water; Pramuk & Gagliardo, 2008); wait 24 hours prior to testing and, if necessary, readjusting.

Removing ammonia

- If there is ammonia present in a system, you can add a product such as Ammolock (which neutralises ammonia by locking it up in a non-toxic form that can subsequently be processed by the biological filter; note that the neutralized ammonia still reads as ammonia with most aquarium test kits; also, it will reduce the pH and O_2 levels a little, and should not be used for more than a week as it will begin to interfere with filtration) or zeolite (but note that if the zeolite absorbs as much ammonia from the system as it can and is "full", it will then release it all back into the system).

Removing nitrate

- Options for removing nitrate from the water include: (1) partial water changes (*refer to section concerning water changes above for recommendations on the proportion of water to remove at one time, frequency of water changes, etc.*), (2) using plants to bind up nitrates in the water, (3) denitrification filters, and (4) denitrification units.
    - Regular partial water changes obviously will not reduce nitrates to very low levels if the water being added to the system already contains high levels of nitrates!
    - Plants can be quite useful in terms of removing nitrate from the water in a system, however, there are biosecurity issues associated with the use of live plants (where did they originate / how were they cultivated? what amphibian pathogens could they have been exposed to on their travels from source to system? can they be treated?).
    - Nitrate removal filters do work, but they use an ion-exchange resin to remove nitrate, so knowledge of the resin being used and what it will be putting into the water is essential to avoid replacing one water quality problem with another.
    - Denitrification units are really only suitable for large systems (larger than most amphibian systems), as they are too fiddly and time-consuming for smaller systems. If used, they must be sized appropriately – the aim is to maintain a very low level of nitrate in the system, otherwise the unit will stop working, so if the DN unit is too big for aquarium, it will get to the point where there is not enough nitrate in the system for the unit to work. DN units also require a very slow flow of water through them, and hence have a very slow water turnover rate. There are two methods: chemi-autotrophic (which use a sulphate-based media and produce sulphuric acid as a by-product, therefore the effluent from the DN unit needs to pass through a calcium carbonate reactor), and heterotrophic (which use a plastic-based media and produce bacterial slime as a by-product, therefore the effluent from the DN unit needs to be put through a skimmer).

Removing phosphate

- Phosphates are usually too small to be removed via reverse osmosis filtration, but they can be removed from source water using dedicated phosphate sponges, pads or granules.
- To remove phosphates that are accumulating in a system, the preferred option is to clean the glass and aquarium furniture, vacuum the substrate, and carry out partial water changes, however, the dedicated phosphate removal media mentioned above or lanthanum chloride ($LaCl_3$) can be used (dose the $LaCl_3$ in-line just before the mechanical filter).

THE SEVEN COMMANDMENTS OF HEALTHY WATER

(Adapted from Odum & Zippel, 2004 *in* Pramuk & Gagliardo, 2008):

1. Use high-quality water in the first place, and test water quality parameters on a regular schedule.
2. Maintain good water quality through an appropriate combination of frequent partial water changes, proper flow-through, and filtration.
3. Clean mechanical filter media at least once a week.
4. Replace chemical filter media regularly.
5. Treat biological media with care; they require oxygen and food (*i.e.* nitrogen) and should not be exposed to water that isn't from the relevant aquarium.
6. Do not overcrowd or overfeed animals.
7. Incorporate live plants into systems whenever possible.

SPECIFIC ISSUES / SITUATIONS

Quarantine aquaria

- Maintaining good water quality is particularly important in quarantine aquaria, or those where animals have exhibited signs of stress or illness, and one way of doing this is to use both a good quality sponge filter and an external filter for each aquarium. → As external filters strip oxygen out of the water (unless bioload is very low), the sponge filter helps to keep the water oxygenated – this is not so important if the filter return is emergent / goes through a trickle bar, but is quite important if the filter return is submerged, which will be the case in situations where an emergent filter return would cause too much disturbance to the surface of the water for the species in question.

Importing aquatic amphibian species / life-history stages

- Imports: When you open the bag, the water degases quickly (it was in equilibrium while the bag was sealed), and the pH rises, which causes any ammonia to become much more toxic. This can be a serious problem given the high densities animals are often packed in for export. → **Solution:** On arrival, open the bag slightly and add oxygen and a product such as Ammolock (so that the ammonia is bound up in case the pH still changes too quickly), then reseal the bag and leave for half an hour before opening properly. Slowly add your aquarium water to the water the animals arrived in to adjust pH and acclimate them to your water chemistry and then net out the animals and transfer them to the aquarium they will be housed in, *never* add the shipment water to your aquaria.

Managing 'valuable' species

- It is a very good idea to maintain at least three separate aquaria for each aquatic species (or each clutch of larvae for species with aquatic larvae) in order to ensure that any loses due to adverse tank effects, equipment failures, human errors, etc. do not eliminate your entire population / clutch. In order to maintain genetic diversity, it may not be desirable to maintain them as completely separate groups, and animals may be moved amongst groups as necessary.

When ambient air & water temperatures differ

- When aquaria are maintained at temperatures different to the ambient air temperature, evaporation can be very high, which will concentrate chemicals in the water.

DISINFECTING AQUATIC SYSTEMS

- ZooSept (1:200 solution) can be used to disinfect aquaria, filters, nets, siphoning equipment, food dishes, etc. – it works virtually on contact and denatures very quickly, and so there is less likelihood of problems occurring due to disinfectant residues; as with all disinfectants, items must be as clean as possible prior to disinfection with ZooSept, as organic matter denatures it. To disinfect a system, fill the aquarium with ZooSept solution and run the entire system (*i.e.* filters, etc.) for 24 hours, then empty, rinse well, fill with 'clean' water and run the system with the filter going to waste, repeat this final step several times. Note: if there has been a problem with Mycobacteria in an aquarium, another disinfectant may be used instead as it not 100% certain that ZooSept kills Mycobacteria.
- F10 (1:125 solution) can also be used in the same manner as described for ZooSept.

NOTES ABOUT DIETS

- 'Malawi bloat' can occur when algivores are fed too much protein (could this happen with tadpoles?).
- For species that feed primarily on algae, Aquarian Herbivore Flake (36.5% protein) is very good, and algae wafers / pellets (~32.5% protein) can also be used – New Era Algae Pellets are particularly good.
- Zoolife Reef Gel is also very good, and can be applied to rocks, etc., for grazers, *but* it is composed of marine algae, so needs to mixed with other foods for freshwater species (*e.g.* hair algae).
- Zoolife Fishvits are another product for marine species, but can be used with freshwater species.

NOTES ABOUT DISEASES, HEALTH ISSUES & TREATMENTS

- Aquatic amphibians / life-history stages expend considerable energy conserving electrolytes, and are at risk of developing potentially fatal electrolyte imbalances when their skin, gills (if present), or kidneys are damaged by infectious disease - this presents as fluid overload.
- As ill aquatic amphibians tend to be at risk of fluid overload, they should be kept in an appropriate electrolyte solution (*e.g.* 10 – 100% amphibian Ringer's) in preference to 'normal' fresh water.
- The use of 10 – 20% amphibian Ringer's solution with aquatic amphibians undergoing antibiotic treatment has been shown to increase survival (Maruska, 1994 *in* Wright & Whitaker, 2001), and it is recommended that

electrolyte solutions are used in conjunction with antibiotic and antifungal treatments, as well as in all cases of potential renal disease, or where skin / gill lesions are present (as electrolytes can be lost through damaged epithelial surfaces – the use of artificial slime products can reduce electrolyte loss).
- Hypertonic (110%) amphibian Ringer's solution can be used in mild cases of fluid overload (*e.g.* oedema) that are either unchanged or getting worse 24 hrs. after starting treatment with standard amphibian Ringer's, or from the beginning if the fluid overload is life-threatening. Hypertonic solutions should not be used for more than four hours without re-assessing condition; if the fluid has reduced in volume, switch to an isotonic or hypotonic solution.
- ***Amphibian Ringer's solution*** (Humason, 1967 in Wright & Whitaker, 2001)

    1l distilled water
    6.6g NaCl
    0.15g KCl
    0.15g $CaCl_2$
    0.2g $NaHCO_3$
    Mix thoroughly, agitate before use.

- ***110% hypertonic amphibian Ringer's solution***

    1l distilled water
    7.3g NaCl
    0.17g KCl
    0.17g $CaCl_2$
    0.22g $NaHCO_3$
    Mix thoroughly, agitate before use.

- See Wright & Whitaker (2001) for alternative hypo-, iso, and hyper-tonic solutions.
- A number of *Mycobacterium* species (acid-fast bacilli) have been isolated from amphibians, and, as mycobacteria are very common in aquatic environments, they are likely to be present in amphibian aquaria (Brownstein, 1984 *in* Taylor *et al.*, 2001). In amphibians, mycobacteriosis frequently presents as gray nodules in the skin, liver, spleen, and respiratory and digestive tracts. The tips and webbing of digits and the lips and mouth are common sites of infection, and lesions may also be present on the skin and / or internally. Wasting or anorexia may also occur (Taylor *et al.*, 2001).
- Melafix is a natural (Tea Tree extract) antibacterial fish remedy recommended for use in instances of damaged fins, fin rot, ulcers, open wounds, etc.; at Durrell Wildlife Conservation Trust, this has been used successfully at recommended dosages with *Rana dalmatina* tadpoles that had severely damaged, necrotic tail fins (pers. obs.).

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