GREEN WATER:
MYTHS, FACTS, THEORIES II

By Norm Meck

This is a sequel to my Sep-Oct 1996 Koi USA article to provide an update on what has been happening since then. Essentially, the events can be summarized as: the myths continue (and this article includes a few more); the facts have even more substantiation; and the theory has slightly changed. I am sure there are many out there who still believe in the myths and I welcome their comments. Although this may get somewhat technical in places, I'll try to hold it to a minimum.

As a recap for those who may have missed the previous article, we are talking about green pond water. Although it is sometimes called an algae bloom, normally the names it is called are unprintable. For some, it seems to happen every Spring (also sometimes in the Fall). For others, it is almost a way of life. A limited number of pond keepers have never or rarely experienced this "wonder" of nature. It is said that the Koi thrive in it, but you cannot see them to tell if they are thriving or not. You have heard many reasons why your water turns green and tried assorted mechanical wizardry and various chemical concoctions to clear it, (which may or may not have been harmful to your Koi), but it is still green. There is a lot of "snake oil" out on the market to clear green water. The basic ecological relationships within even a small pond are extremely complex and the more knowledge one acquires about these relationships, the more one realizes how much is not known. Reading this article may not keep your water from going green but knowing more about the processes involved may provide some indications as to the cause and possible remedies.

First of all, what is it? Green water is caused by an excessively large number of tiny organisms in the water. Called phytoplankton, these minute plants are part of the algae family that has thousands of distinct species found in water (and ice) throughout the world. These organisms are very small, with the most common ones found in our ponds being around 15 microns (0.0006 inches) in diameter. All pond water contains large numbers of different kinds of these plants and other microorganisms. Water that appears to be crystal clear just doesn't have as many. Although there are many different species of organisms in any pond, I have found that there are a very limited number of species that predominate. You probably don't care what their actual names are, and I can't pronounce them, let alone spell them. For now, we will just lump the most predominant into two categories of interest and ignore the rest. The first category contains the single (or few) celled plants responsible for the algae blooms, which I will refer to as bloom algae. The second category will be called string algae, and consists of the multi-celled, filamentous plants that grow on the walls of the pond (and thrive on the waterfalls). A limited number of pond water samples from outside the local area were observed to contain basically the same mix of predominant species, but there may be different dominant species in other localities.

There are three ways of controlling unwanted plants, i.e. weeds, just as in your garden. They can be: starved of the necessities for life to prevent them from multiplying; removed; or outright killed. Our problem is to find a way to do one or more of these without harming our Koi (and any desired plants) that are sharing this environment. Let's review the common myths and check out the facts.

Perhaps the most controversial myths involve starving the algae of the necessities of life. Algae have specific requirements for growth just as any other plant. ***Liebig's Law of the Minimum***, states that "**growth proceeds only as rapidly as the least available necessity of life allows**." If we can remove or reduce one or more of the required items, algae cannot flourish. Unfortunately, each species of algae has slightly different nutrient and environmental requirements. Besides the primaries of sunlight, suitable temperature, pH, and salinity ranges, all are known to need elemental Carbon, Hydrogen, Oxygen, Nitrogen, Phosphorus, Iron, Calcium, Magnesium, Copper, Manganese, Zinc, and Molybdenum. In most cases, each of these elements are required to be in an inorganic form. Many of these are also requirements of the Koi so we can't mess around with them very much. Some of the required elements have minimum concentration values that are very small. Even if we were successful in removing a critical element, a light rainstorm or even a windy day can add more than is necessary back into the pond. Don't forget, we also go out and throw food into the pond a couple times a day. Often, an attempt to control one element will change the concentrations sufficiently to cause a different species of algae to thrive. Here are two widely believed myths that involve Liebig's Law of the Minimum.

MYTH: Pond algae blooms are primarily related to various nutrient concentrations in the water.

FACT: There is no evidence to substantiate any relationship between nutrient levels and the inception or termination of the common algae blooms in most Koi ponds. Quite to the contrary, the measurable nutrient levels are normally so high, most questions should be why the algae bloom is not continuous. Commercial laboratory analyses consistently show very high concentrations of all required nutrients. These concentrations are always much higher than could be expected to prevent such an event. Further, most of these nutrient concentration levels actually show a slight increase after a heavy bloom subsides.

This myth arises from invalid extrapolations and application of true scientific findings based on studies of large lakes and oceans. An excellent case can be made for a relationship between algae blooms and nutrient levels within the open areas of large bodies of water. Lakes and oceans become stratified with various areas having different nutrient, oxygen, and temperature levels, hence varying population conditions. Most of these scientific findings just simply do not apply to the essentially closed environment of an established, circulating Koi pond. Our ponds, in which the water is continually mixed and nutrients are continuously added, are much more similar to laboratory experiments where algae samples are grown in test tubes and beakers, rather than large lakes or oceans.

MYTH: Providing shade over the pond will prevent an algae bloom.

FACT: It is true that algae needs light to grow and reproduce. But what is interesting is the small amount of light that is actually required. Controlled experiments using reduction in sun light of 90% still show significant algae growth. I can cite many examples of ponds that are heavily shaded but quite green and just as many others with direct sun exposure that have no algae bloom problems at all. There are also several examples of ponds located inside buildings that receive almost no sun light, yet are pea soup green. There have been positive results reported of completely covering a pond suffering from green water with an opaque plastic cover for 5-10 days. I'm not too sure what the Koi think about this but it is obviously not an acceptable permanent solution. I do recommend providing shade over a pond, but more for temperature stability than for algae control.

Now let's look at the myths involved with removal of these weeds.

MYTH: A mechanical filter system will remove bloom algae from the pond water.

FACT: It is impractical to remove these weeds by mechanical means. As we saw above, they are so tiny that they will pass through any feasible mechanical filtration device as if it wasn't even there. If the filter was fine enough to capture the bloom algae, it would plug up in minutes with the other, much larger, particulate matter in the water.

MYTH: A flocculent treatment of the pond water will clump the algae together into large enough sizes that the filter will remove them.

FACT: Flocculents only have a very weak effect on the living algae cells but can be effective in causing some organic waste and inorganic particles to clump. Further, most flocculents are alum based whose principal component is aluminum. There are no known studies of the long term effects of aluminum on Koi.

MYTH: A major water change out will clear the bloom algae.

FACT: Although a major water change out will temporarily remove a portion of the bloom algae, it will actually make the situation worse and the algae bloom will normally increase shortly after the water change.

Now we are left with the killing solution to look at. We obviously could pour a large amount of chlorine or arsenic into our pond and either would do an excellent job of killing the algae but there would also be a similar undesirable effect on the fish and other desired pond inhabitants. There are many so-called algicides on the market (and many more not available in the U.S. due to environmental regulations). Most of those available are copper based. Although those containing chelated copper may be less toxic to fish, it has been shown that the long-term effect of copper build-up in Koi is a problem. Dosages are critical. Too much will kill the fish; too little will not do anything (except maybe long term side effects to the Koi). I cannot overemphasize: BE EXTREMELY CAREFUL OF ANYTHING YOU PUT INTO YOUR POND!

MYTH: Addition of salt to the water will kill the bloom algae.

FACT: The predominant species of algae in our ponds are only slightly affected by salinity levels that can be tolerated by the Koi. Some species of algae cannot tolerate more than about 1 ppt (part per thousand) of salt in the water while others cannot survive if the salinity is less than 1 ppt. Neither of these particular species normally contributes to an algae bloom. I am a proponent of adding some salt to the pond, but this has no significant effect on the algae.

Nothing says WE have to kill the bloom algae; how about having another creature act as a hit man for us?

MYTH: The nitrification bacteria in the biologic filter kill and eat the bloom algae.

FACT: The nitrification bacteria are chemolithotrophs which means they use only inorganic chemicals as their energy source. In addition to their basic requirements of oxygen, carbon dioxide, and a few trace minerals, they are very restricted to diets of only ammonia and nitrite respectively.

There is another group of bacteria in the filter that one hears very little about. These are the heterotroph (chemoorganotroph) bacteria which consume dead organic matter (you may remember references to them in some of Joe Cuny's articles). Technically, these organisms conduct a process called aerobic bacterial decomposition but it is more commonly known as decaying or rotting. This is essentially the same thing that takes place in a compost heap or what happened to that fish that jumped out of the pond and was not discovered until several days later. It is easy to tell if this process is the desired aerobic (oxygen present) or anaerobic. Aerobic conditions do not produce that strong, characteristic odor. These heterotroph bacteria cannot consume any live material, only the remains. We will discuss more about them later.

We now know what makes up an algae bloom and we know it often goes away, but why does it start and why does it end? This leads to the theory and what this article is really all about.

The previous article discussed the circuitous route that led me to conduct the original experiments. I will recap one particular group of experiments but there were many others with interesting results. Considering that my laboratory was really a kitchen and that the equipment, controls, and analysis were not nearly as sophisticated as those used by the microbiologists, the results were surprisingly consistent and repeatable. These experiments are simple enough that they can probably be repeated by almost anyone. Each involved a clear glass jar (mostly ex-mayonnaise but sometimes peanut butter) filled with various water samples. Added to the samples were a couple of drops of liquid nutrients (house plant fertilizer), and a measured amount of "starter" containing both bloom algae and other organisms taken from ponds suffering the green water malady. The jars were placed in a sunny kitchen window, stirred at least twice daily, and the bloom algae growth rates were determined using a biological microscope at 140x. No temperature controls were maintained.

In the first set of tests, samples consisted of distilled water, dechlorinated tap water, and local area well water. All were aerated and nutrients and starter were added to each. Bloom algae growth rate was very rapid in all samples, more than quadrupling each day.

A second set of tests was made with the water samples taken from clear, established ponds. The first of these samples was filtered through a coffee filter to remove most particulate matter but not any of the microorganisms. A second sample was then additionally passed through a micron filter to remove any microorganisms larger than 2 microns. Identical quantities of nutrients and starter as in the first test set were added to both samples. Most of the starter bloom algae added to these samples died within just a few hours and ended up as sediment on the bottom of the containers.

This was a startling observation. Rapid bloom algae growth was observed in all of the first test samples. Not only was no growth observed in the second test samples of established pond water, but the starter bloom algae died rapidly. The only conclusion that can be reached is that:

THERE IS SOME COMPONENT IN CLEAR ESTABLISHED POND WATER THAT IS TOXIC TO THE BLOOM ALGAE

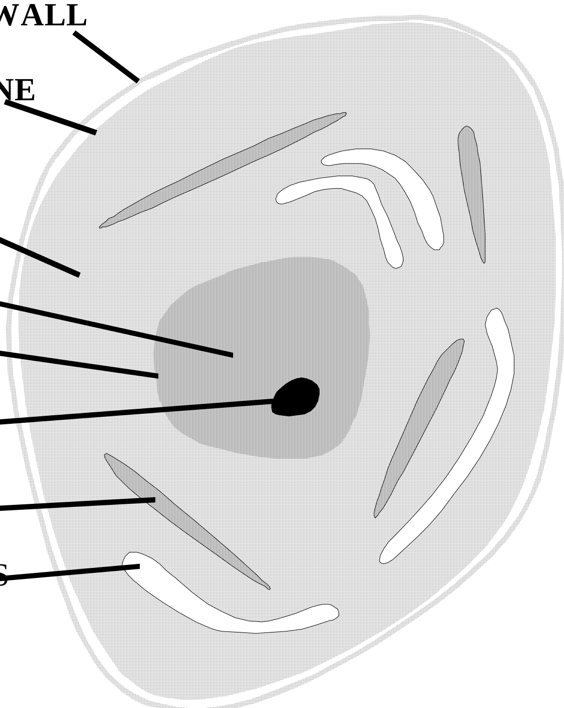
A third set of tests was conducted using the same procedures as the second test set except the filtered pond water samples were diluted with varying amounts of aerated distilled water. The result of a 1 part distilled water to 1 part pond water dilution was the same as for the second test set, i.e. the starter bloom algae died quickly. At 2:1, the starter bloom algae did not immediately die but no significant growth was observed. At 3:1, some growth was observed but at slower rates than the first test samples. At 4:1, rapid bloom algae growth was observed, essentially the same as in the first test set. These results suggest that whatever this toxic substance is, when it is diluted down by about 75%, it is no longer an effective inhibitor.

THEORY: Based on these semi-controlled experiments, other experiments and observations, and from researched literature, this is what I think is actually happening in our ponds:

When algae dies and is subjected to aerobic bacterial decomposition by heterotroph bacteria, a by-product of this process is a substance, released into the water, that is toxic to the living algae.

This theory is exactly the opposite of competition effects. Remember the myths based on *Liebig's Law* involve the removal or reduction of some factor, such as nutrients, or light, required by the bloom algae. This theory states that something is naturally ADDED to the water that kills the bloom algae. A similar example of this effect is penicillin, a substance that is released by one microorganism (a form of yeast), which is toxic to other microorganisms. The term for a substance released by one microorganism that is inhibitory to another microorganism is called an antibiotic and that name applies here as well. (Those familiar with the previous article will note the change in the assumed source of this antibiotic as now requiring the intermediary heterotroph bacteria process as opposed to being directly produced by the plants themselves.)

Before we look at the details of the theory and what I believe are the actual processes, let's look a bit closer at the structure of these single celled plants responsible for the algae blooms. The drawing is not intended to represent any particular species of algae, just a general example of the cell structure that would make up most types.



TYPICAL ALGAE CELL STRUCTURE

We are not interested in all the details of this thing, but we will examine some of the characteristics of three of the primary components to lay some groundwork for the theory. First is the cell wall which is peculiar to plants (animal cells do not have a cell wall). Different plants have slightly different chemical makeup of the cell walls, but for all, it is a relatively rigid layer of cellulose that strengthens the cell and is what provides the structural support for the higher orders of plants such as trees. One interesting organic component of the cellulose is Lignin, a complex aromatic polymer that provides the primary strength of the cell wall. An interesting characteristic of the Lignin is that it is impervious to anaerobic (no oxygen present) decomposition. Coal (lignite) would not exist today if it were not for this characteristic. In an aerobic (oxygen present) environment, the lignin in a dead cell wall is readily broken down by microorganisms (i.e. heterotroph bacteria).

The cell wall protects the very thin, highly flexible, but structurally weak Cytoplasmic membrane that lies under the wall and surrounds the interior of the cell. The cell interior, the Cytoplasm, consists of a solution of salts, sugars, amino acids, vitamins, and a wide variety of other soluble materials in water. Since the Cytoplasm has a higher solute concentration than the water surrounding the cell, osmosis causes water to pass from outside the cell through the relatively permeable cell wall, continue through the cytoplasmic membrane, and dilute the cytoplasm. This builds up pressure within the cell until it equalizes to the effective osmotic pressure and, if not for the rigidity of the cell wall, the cell would burst. Other chemical compounds necessary for the life of the cell are selectively passed through this membrane and waste products are evacuated through it.

So, now that we know a bit more about the insides of this single celled plant, here is what I believe is the basic sequence of events that occur in our ponds. When an algae cell dies (for whatever reason), the cell wall structure can no longer support the osmotic pressure of the water entering the cell and the cell bursts. (I have observed this happen under a microscope and it is similar to a kernel of popcorn popping). The now exposed cytoplasm is quite sticky and has a natural tendency to adhere to anything it might come in contact with. The internal surfaces of the bio-filter media are a natural trapping location for these cells and combined with the oxygen rich water, a healthy environment is provided for the growth of heterotroph bacterial colonies to decompose the dead cells. Although the bacteria prefer to consume the nutrient rich cytoplasm (and almost any other rich organic waste), when that is consumed they will then work on the cell walls. A waste product of the decomposition process of the cell walls is an antibiotic that is toxic to algae. The presence of this antibiotic in the water causes other algae cells to die, the heterotroph bacterial colony increases in size as more "food" becomes available, and as more antibiotic is produced, more algae dies. This continues until an equilibrium point is reached where one of the requirements for the sequence becomes limiting (remember good old *Liebig's Law*). If the limiting factor is the amount of "food" for the heterotroph bacteria, the water has relatively few remaining algae cells and appears quite clear. If the limiting factor is the amount of space available for the bacterial colonies and the capture of the dead algae (i.e. insufficient amount of filter media) then the water may still have sufficient algae concentration to retain some level of turbidity. This turbidity level (how green it is) will be determined by a combination of all the different characteristics of a given pond and filter system.

Some of the exact details of the processes involved are not known, but here are some guesses about the more interesting ones. These conjectures are being used to formulate further controlled experimental procedures as attempts to verify them.

HUNCH: The antibiotic may be an enzyme produced by the bacteria to help them breakdown (digest) the lignin in the cell walls, and that which ends up in the pond water is just a surplus from the process. There is a high probability that the antibiotic produced is a phenol based compound but the exact chemical composition is not yet known. There are indications that it has a lifetime of up to three to four days after being created. What causes it to lose effectiveness is unclear but it may be consumed in the process of killing algae cells or, possibly, it simply oxidizes.

HUNCH: The exact effect of the antibiotic on the algae is also unknown. It is suspected that it may weaken the cell wall causing the cell to burst from the internal osmotic pressure.

HUNCH: The antibiotic appears to be effective against many species of string algae as well as the bloom algae. It does not seem to have as much effect on the string algae which is only partially submerged or within a high flow area, i.e. in a splashing brook or around a waterfall. This may have to do with contact time requirements. The short blackish-green mat algae found on the walls of a "healthy" pond is composed primarily of dead string algae which is also believed to be a result of control by the antibiotic. Further, this mat area may also be providing a portion of the antibiotic as it is being broken down by the heterotroph bacteria.

There are many more interesting observations that this theory supports but I do not yet have enough substantiation to even include them in the hunch category, so they will be saved for a later time.

From additional experiments, I have found that the heterotroph bacterial colonies require much more space within the bio-filter media than the nitrification bacteria. For a typically effective bio-filter, these experiments demonstrate that around 90% (or more) of the media internal surface area may be required for the heterotrophs and only about 10% for the nitrifiers. There are indications that there is also some competition between the various bacteria types for this space but the details are still hazy. Almost any biologic filter that is large enough to support the heterotroph bacterial colonies will be more than adequate for the nitrification processes. The nitrification bacteria are consuming the molecular particles of ammonia and nitrite and the heterotrophs are working on many other types of organic matter as well as the dead algae cells. Since there is so much more of the organic material, this probably accounts for the larger space requirements and why the heterotroph action appears to be a considerably slower process. This aerobic bacterial decomposition process is very similar to that observed in a compost pile and the residual final waste is what makes up the majority of that brownish sediment (detritus) that we periodically have to clean out of our filters.

Reports and preliminary experiments show that barley straw has a similar enough chemical makeup to algae that when it is subjected to the same aerobic bacterial decomposition, a comparable, if not identical, antibiotic is produced. This is leading to further experiments into how to effectively use this characteristic and also attempts to isolate and/or produce this antibiotic.

Let's look at how this theory explains many of the common observations of pond keepers.

The antibiotic production sequence is exponential. That is, as more antibiotic is produced, more algae dies providing material for more antibiotic production. This can explain why a pond which has been green for some time is often observed to clear almost overnight.

After a pond clears, a slight brownish or tea colored tint is often observed for a few days. This is believed to be due to a higher concentration of the antibiotic than normal. As the antibiotic level drops to its equilibrium level, this tint usually goes away.

A large water change out will remove a significant amount of the antibiotic that is active in the pond. The bloom algae then gets the upper hand and the pond goes green until sufficient replacement antibiotic can be produced to clear it again.

The production of this antibiotic is a continuing and fairly lengthy process. If the filter media is cleaned (which removes the dead algae cells that are being consumed and additionally removes a significant portion of the heterotroph bacteria colonies), the production rate of the antibiotic drops. Shortly thereafter, the amount of the antibiotic remaining in the water decreases and, bingo, we have green water again.

Often, the water will go green for a short while following a spawning. The heterotroph bacteria prefer the nutrient rich waste from the spawning and will naturally consume it prior to the dead algae cells, thus temporarily reducing the antibiotic production.

In the Spring, as the water temperature increases, the algae become active at a slightly lower temperature than the heterotroph bacteria. The algae start multiplying rapidly giving an algae bloom and until things warm up a bit more and sufficient time passes for the heterotrophs to get up to speed, the water often turns green. In the Fall, as the temperature declines, it reaches a point where the bacterial activity slows down. The antibiotic production decreases, thus removing control over the bloom algae which is still active. The result is Fall green water until the temperature drops below the bloom algae high activity range. If sufficient antibiotic is in the water during either of these temperature change cycles and/or the temperature changes are rapid enough, no algae bloom occurs.

The dead algae cells are most often trapped near the external surface of the filter media, not deep inside it. This is why a filter with a large flow area works better than a smaller one (even if it has a greater total volume of media). As the layer of dead algae builds up on the media, the outer portions of this layer isolate the underlying regions from oxygen and the decomposition (antibiotic production) process proceeds more slowly than if the material was spread out over a larger area. This reveals why multiple biologic filters should be run in parallel as opposed to series for maximum effect. It also leads to an empirical observation that around one square inch of traditional filter cross section flow area is appropriate for each gallon of water in a typical Koi pond.

Bubble bead or similar type filters do not generally have sufficient internal surface area to support the heterotroph colonies necessary for antibiotic production although they can provide the area necessary for the smaller nitrification colonies. They do an excellent job of capturing the dead algae and other solids. During the frequent backwashing processes, however, the dead algae and much of the heterotroph bacterial colonies are removed from the system giving insufficient time for the antibiotic to be produced. This is why ponds using these type filters almost always require an ultraviolet system to handle the green water problem. A properly sized UV system will do a good job on eradicating the bloom algae. It will not affect the string algae, only the phytoplankton that actually pass through the unit. There are also some indications that the UV radiation destroys or at least weakens any antibiotic action.

CATCH 22 HUNCH: I left this for the very last so that all the die hards who managed to read all the way through this thing can consider the implications, draw their own conclusions, and realize how many new questions it raises. As such, I will only make the statement that the prime candidates for the heterotroph bacteria that produce this antibiotic are from the aeromonas and/or pseudonomas families.

Help... As I continue this investigation into Koi pond algae blooms, I would appreciate any information that might substantiate or, even more important, examples that are believed to refute this theory (normeck@pacbell.net). Thanks to all that responded to the earlier article.