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Barr Report

Barr Report

Dissolved Inorganic Carbon (DIC)

Special points of interest:

- Feature Article "Dissolved Inorganic Carbon"
- "Carbon exists in inorganic and organic forms ..."
- "Dissolved inorganic carbon (DIC) is the sum of all carbon present as CO_2, H_2CO_3, and CO_3 and represents the primary source of carbon for photosynthesis by aquatic organisims ..."

Carbon is required for life on Earth, including life in aquatic ecosystems (Rheinheimer 1992). All living organisms need carbon as a food source. The importance of carbon cycling is that the processes involved form important links between the abiotic (non-living) and biotic (living) components of the aquatic ecosystem (or any ecosystem). This is in large part due to the ability of carbon to form strong bonds to other non-metals such as hydrogen, nitrogen, oxygen, sulfur and the halogens (Zumdahl 1993). Under certain conditions metals such as iron and manganese, or nutrients such as phosphorus or nitrogen, can become adsorbed (or attached) to carbon molecules, temporarily rendering these unavailable to aquatic organisms (Figure 1).

The cycling of carbon involves transitions of carbon between organic and inorganic states.

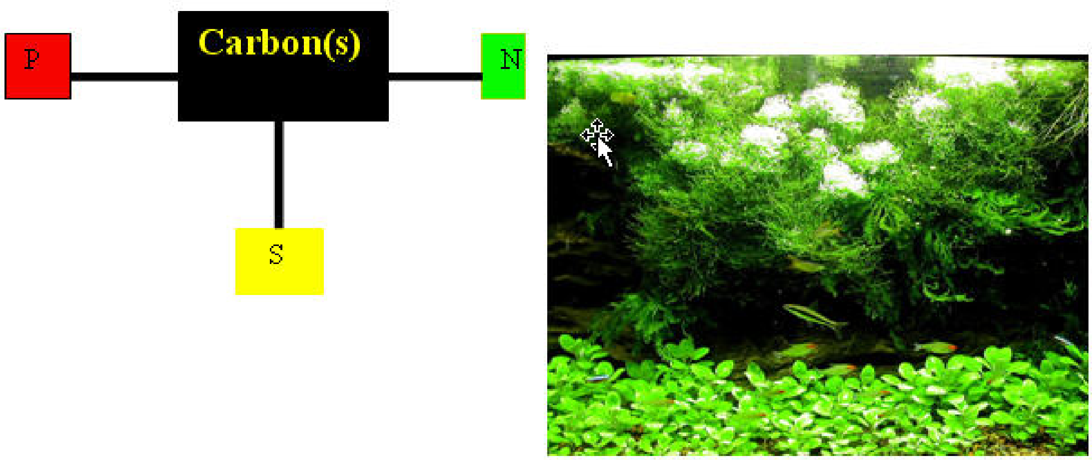

Figure 1

Carbon exists in inorganic and organic forms. Organic forms typically consist of long chains or rings of carbon atoms which constitute a part of living matter or part of substances derived from living matter such as decaying vegetation and humic acids. Compounds such as the oxides

Continued on page 2

Inside this issue:

Dissolved Inorganic Carbon (DIC)

In fully planted aquariums, free CO2 becomes limiting to aquatic macrophytes under higher light intensity.

of carbon (e.g. CO_2) and carbonates (CO_3) are considered to be inorganic substances (Zumdahl 1993). The cycling of carbon involves transitions of carbon between organic and inorganic states. These transitions are influenced by, and themselves influence, a number of physico-chemical factors such as light, temperature, dissolved oxygen, pH, redox potential, ionic composition of the water, as well as biological factors such as productivity. Next month's issue of the Barr Report will discuss organic carbon. Figure 2 shows a carbon cycle within a typical wetland (adapted from Reddy 2004).

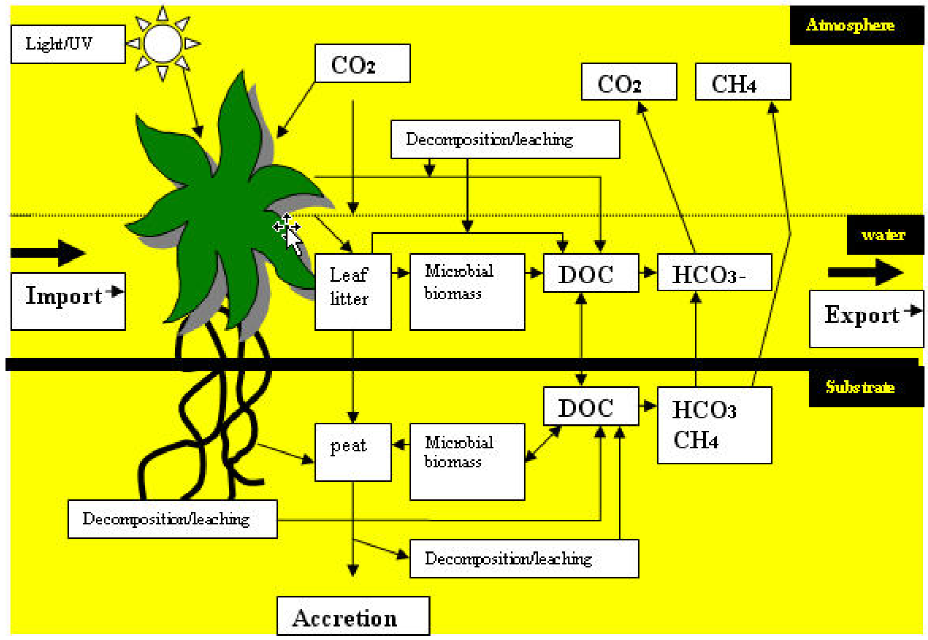

Figure 2

"All Organisms need carbon as a food source."

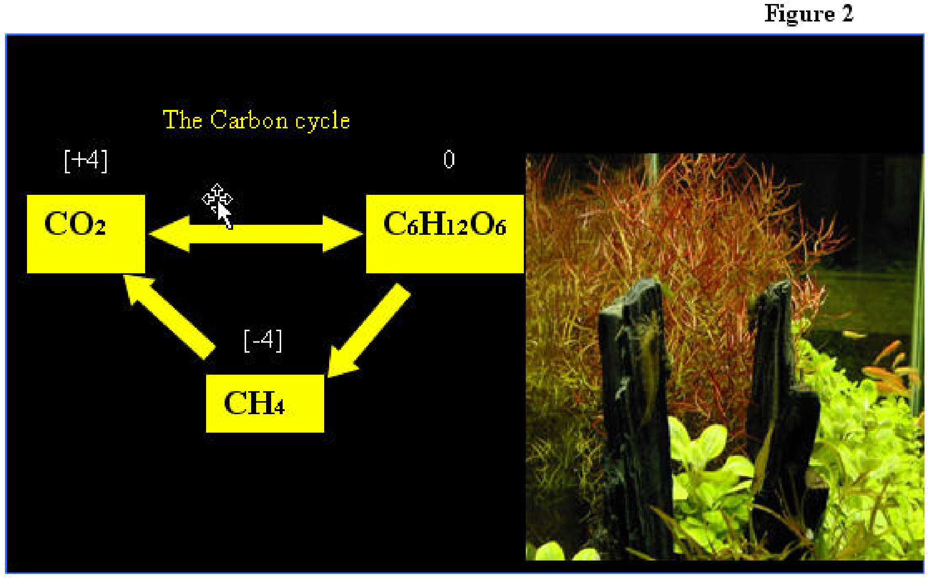

Figure 3

It's not a missile, but a Submersed Aquatic Macrophyte

Continued on page 3

Dissolved Inorganic Carbon (DIC)

Figure 3 shows the various carbon transformations in a wetland. CO2 enters the cycle and is incorporated into submersed aquatic Macrophytes (and other plants and algae); the other forms of carbon will be addressed in next month's issue of the Barr Report. Figure 3 shows that plants assimilate and reduce CO2 into sugars. When these sugars [C6H12O6] are decomposed without oxygen, they yield CH4 (methane) through microbial processes and oxidized into CO2 as it travels up into the aerobic zone. If they are decomposed in the presence of oxygen, then it yields CO2 which can be reassimilated by the plants.

DIC

Dissolved inorganic carbon (DIC) is the sum of all carbon present as CO_2, H_2CO_3, HCO_3 and CO_3^{2-} and represents the primary source of carbon for photosynthesis by aquatic organisms. In most bodies of water, there is ample carbon available for use in photosynthesis and only under certain conditions (such as soft water or extremely high productivity) does DIC become limiting. Where there is high SAM density, CO_2 is removed rapidly in the presence of light. There is a close correlation between ample DIC and distribution of SAM's in natural ecosystems (Raven 1970). In fully planted aquariums, free CO_2 becomes limiting to aquatic macrophytes rapidly under higher light intensity. When this occurs, many SAM's utilize bicarbonates, HCO_{3-}, as a source for carbon (Equation 1). It is estimated that 50% of submersed aquatic macrophytes can utilize HCO_3 under high light low CO_2 conditions.

HCO_{3-} + Carbonic anhydrase (CA) -----> CO_2 + OH- eq 1

All plants and algae *prefer* CO_2 over HCO_3 and it takes approximately one week for both to acclimatize to a given steady level of CO_2 (Bowes 2003, Taiz and Zieger 1998). Bicarbonate can be used under limiting conditions and plants can do this directly as with the case using carbonic anhydrase(CA) which is *direct* bicarbonate use or they can utilize indirect bicarbonate use. *Indirect* bicarbonate utilization uses a proton pumping mechanism where the plants pumps out large amounts of H+ on the abaxial surface of the leaf(the bottom surface) and which lowers the pH and reduces the bicarbonate to free CO2 whereby the SAM then takes up the carbon in the CO2 form (Bowes 2003).

"Bicarbonate can be used under limiting conditions and plants can do this directly ..."

Free CO_2 is usually present in surface waters at concentrations of < 10 ppm and is often present in well and tap water at higher concentrations. This is due to microbial CO_2 release in the soil as the water from the surface accumulates the respired CO_2 and has no way to escape or equilibrate underground. Additionally, cooler water possesses more dissolved gases than warmer aquarium water. High excess CO_2 in water can have deleterious effect on locomotion and metabolic activity in many animals so measurement of total inorganic carbon is an important variable in water management. While excess CO_2 is often considered a negative parameter for aquatic ecosystems, when SAM's are present in high density, it allows rapid growth and high levels of the by product O2. This high O2 level mitigates the effect of the elevated CO2 levels (within

Continued on page 4

Dissolved Inorganic Carbon (DIC)

"In locations where there is ample rich CO2 in the water, there are often vibrant stands of [Aquatic Life] growing actively ."

limits) within the respiration cycle of other organisms. High densities of fish and animals are found in naturally occurring waters where elevated CO2 levels are present (Florida and Brazilian freshwater springs) and this has a pronounced effect on the plant production.

Table 1 shows the various forms and uses for carbon. The primary focus initially will be the DIC fraction. The second chapter in the two part series will address the organic fraction, DOC (Dissolved organic carbon) and POC (Particulate organic carbon).

	Particulate	***Dissolved***
Organic	Living organisms	Soluble organics: amino acids
	Dead organic material	sugars
		DOC (dissolved organic carbon)
Inorganic	$CaCO_3$	DIC (dissolved inorganic carbon): CO_2
	carbonates of Mg, K, Na, etc.	H_2CO_3
		HCO_3^-
		CO_3^{2-}

Table 1

Some research will mention the ratio of CO_2:H_2CO_3. This is roughly 400:1 and most treat this fraction as all CO_2 (Lea 2000).

Photosynthesis

Photosynthesis consists of light reactions and dark reactions. This is the overall pathway simplified from light to sugar:

Light → produces light reactions in the autotroph → produces ATP, NADPH, O_2 → for use in reductive pentose cycle or Calvin cycle → to reduce CO_2 → to sugars.

We will be looking at the [**CO_2 → "sugars"**] portion of this process: CO_2 + ribulose 1,5-bisphosphate (5-Carbon) → the enzyme: D-ribulose 1,5-bisphosphate carboxylase → produces two 3-C sugars (6 total Carbons from

Continued on page 5

Dissolved Inorganic Carbon (DIC)

the original 5) Rubisco catalyzes the reaction between ribulose bisphosphate (RuBP: a five-carbon sugar bisphosphate) and CO2 to give two molecules of 3-P-glyceric acid (PGA: a three-carbon acid). The PGA then goes on with ATP and NADPH to form sugar-phosphates in the PCRC cycle.

RuBP + CO_2 → 2 x PGA → photosynthesis (PCRC Cycle).
Rubisco

This process is called the photosynthetic carbon reduction cycle(PCRC). This involves electron and proton transfer reactions, complex membrane systems, protein complexes, electron carriers, lipid molecules, all surrounded by water. Submersed Aquatic Macrophytes (SAMs) use Carbon dioxide (CO_2) to make sugar phosphates by using the products of the light reactions: ATP and NADPH. ATP and NADPH are used to reduce CO2 to sugar phosphates. These sugar phosphates are the subunits used to synthesize *all the plant's organic molecules*. This cycle is found in all autotrophs organisms (except for a few bacteria). The key enzyme in this process is rubisco (ribulose bisphosphate carboxylase-oxygenase). With the exception of the carbon fixed by some prokaryotic organisms, most of the carbon fixed on Earth is processed by the Calvin cycle.

"High [O2], low [CO2], high temperature and irradiance enhance photorespiration, and thus reduce net photosynthesis…"

Adaptation to available CO2 concentrations

The concentration of rubisco, the carboxylating enzyme of the Calvin cycle, is generally high. For example, it accounts for 50% or more of the total protein in plant leaves, and its concentration within chloroplasts is extremely high (approximately 0.2 g/ml). It constitutes some 30% of the total protein in many leaves for which reason it is of considerable interest in relation to the nitrogen nutrition of plants. Plants from elevated CO2 had significantly higher (52%) rubisco than plants from ambient CO2 when measured in their respective growth CO2 concentrations. Elevated CO2 decreased leaf soluble protein (40-52%) and rubisco (30-55%) contents, increased soluble sugar (52%) and starch (44%) (Jacob and Drake, 1994). This means that SAMs adapt under high CO2 levels allocate their resources to the production of food and storage sources of energy rather than uptake enzymes. This adaptation takes approximately one week's time (Madsen, Bowes, Maberly, 1996). This shows how plants are able to adapt to *different* aquatic environments allowing aquarist to grow SAM's in non Carbon and Carbon enriched aquariums (an important issue for aquarist is maintaining a stable supply of the form of carbon as well as the concentration) as well as how they can adapt their enzymes.

The Rubisco enzyme is the first step in the carbon reduction cycle and is the way by which inorganic carbon enters the biosphere as organic carbon. It is

Continued on page 6

Dissolved Inorganic Carbon (DIC)

a large, sluggish enzyme with a turnover time of 2 s^{-1}. It occurs in the stroma of the chloroplast and is a major limiting factor in terrestrial photosynthesis (part of mesophyll resistance). Microphytes (algae) such as epiphytic algae on the surface of SAM's leaves and blades increase this diffusional distance, thus resistance (as well as reduce the available CO_2 and foliar nutrient and light availability). Additionally, most microphytes (algae) posses only one cell layer surface between the environment, while SAM's typically have several cell layers distance to transport CO_2 to the photosynthetic cells. It should be noted that microphytes are epiphytes upon each other as well as SAM's, therefore they can cause availability declines within both groups much like SAM's can with one another. This resistance is further increased in the thick viscous liquid water medium, although SAM's make up for this a number of ways through thin finely dissected leaf morphology, reduced cuticle thickness, no requirement to close stomata aperture (effectively keeping the stomatal resistance at its lowest level) for water evapotranspiration (we assume there is ample water in an aquarium or lake!), root uptake of CO_2 and CAM and C4 photosynthetic pathways. Adding to the problem of low CO_2 for Rubisco to fix CO_2 efficiently is gas diffusion from the atmosphere into the water. Water is a dense polar solvent. CO_2 and O_2 diffuse 10,000 times slower than in air. This greatly reduces the plant's ability to make the basic building blocks and is often the main limitation in natural lakes and streams. In locations where there is ample rich CO_2 in the water, there are often vibrant stands of SAMs growing (Raven 1970).

Photorespiration

Since CO_2 and O_2 are similar rubisco's active site, the enzyme has a hard time distinguishing between them, and so O_2 can become a competitive inhibitor of rubisco with respect to CO_2. So in the presence of atmospheric [O_2] and [CO_2] the enzyme (and photosynthesis) is inhibited by up to 50% (Chollet, 1977). In addition, rubisco catalyzes the reaction of O_2 with RuBP to form one molecule of PGA and one of P-glycolate (a two-carbon acid). When this happens, no C is added to the organic-C pool of the plant, and even worse the P-glycolate is metabolized in the Photorespiratory Carbon Oxidation (PCO) Cycle and releases previously fixed CO_2.

RuBP + O_2 $\xrightarrow[\text{Rubisco}]{}$ PGA + P-glycolate → photorespiration (PCO Cycle).

Organic-N is released as ammonium and has to be refixed into organic-N – an energetically very expensive process (uses lots of ATP) in photorespiration. Plants that just use the PCR cycle, and thus also photorespire, are called C3 plants (C3 photosynthesis), because the first compound formed is PGA (a three-carbon acid). They constitute the majority of autotrophic species on the planet. High [O_2], low [CO_2], high temperature and irradiance enhance photorespiration, and thus reduce net photosynthesis. One of my studies (Barr 2003) involved various combinations of O_2 and CO_2 gas to investigate whether high O_2 levels had a significant impact on epiphytic attached algae growth on glass slides. The results show similar Chlorophyll *a* levels, but different algae species compositions in each of the various combinations

Continued on page 7

Dissolved Inorganic Carbon (DIC)

Test one	*Ambient low CO_2*	*Ambient low O_2*
Test two	**Ambient low CO_2**	High O_2 [150% saturation at 25C]
Test three	**High CO_2 (25ppm)**	Ambient O_2
Test four	High CO_2 (25 ppm)	High O_2 [150% saturation at 25 C]

Table 2

In aquariums, high CO_2 and O_2 levels are the most commonly found conditions where CO2 or carbon enrichment is used. It would appear that algae epiphytes are adapted photorespiration and these conditions can change the algae species composition but not the production significantly under these conditions. SAM's also adapt well to high levels of O2 and photorespiration (Bowes 2004).

CO_2 and O_2 differences

An understanding of the mechanism of CO_2 fixation requires knowledge of the physical and chemical properties of CO_2, particularly those related to its interaction with water. The amount of any gas dissolved in water is proportional to its partial pressure (P_{gas}) above the solution (Henry's law) and its Bunsen absorption coefficient (α). The Bunsen absorption coefficient is the volume of gas absorbed by one volume of water at a pressure of 1 atmosphere and is temperature dependent, decreasing as the temperature rises. The solubility of a gas therefore decreases with increasing temperature. Thus, for a given temperature,

$$[gas]\ \mu M = P_{gas} \times \alpha \times 10^6/V^\circ$$

Where V_0 is the normal volume of an ideal gas at standard temperature and pressure ($V_0 = 22.4$ L mol^{-1}). We can calculate the partial pressure of a gas by multiplying the mole fraction of the gas by the total pressure. The mole fraction of a gas is its partial volume divided by the total volume of all the gases present. Thus, the mole fractions of CO_2 and O_2 in air are 0.0345% and 20.95%, respectively. At sea level, atmospheric pressure is about 0.1 MPa, yielding the partial pressures of CO_2 and O_2 at 3.4×10^{-5} and 2.1×10^{-2} MPa. From these values and those of α, the corresponding solution concentrations of CO_2 and O_2 can be computed by the equation given above. The table below presents values for these concentrations at different temperatures (Table 3). These values place considerable constraints on carboxylation. As a carboxylase, rubisco must be capable of operating efficiently even at the rather low concentrations of CO_2 available to it. Rubisco also functions as an oxygenase in photorespiration, so the solution concentration of O_2 is also important. Because of the different temperature dependences of the Bunsen absorption coefficients $\alpha(CO_2)$ and $\alpha(O_2)$, the concentrations of these two gases vary with temperature such that the ratio of CO_2 to O_2 decreases as the temperature increases. This effect is important biologically, because as the temperature increases, the ratio of carboxylation to oxygenation catalyzed by rubisco decreases and the ratio of photorespiration to photosynthesis thus increases. This slows plant growth.

Continued on page 8

Dissolved Inorganic Carbon (DIC)

Temperature (°C)	α (CO_2)	[CO_2] (μM in solution)	α (O_2)	[O_2] (μM in solution)	[CO_2]/[O_2]
5	1.424	21.93	0.0429	401.2	0.0515
15	1.019	15.69	0.0342	319.8	0.0462
25	0.759	11.68	0.0283	264.6	0.0416
35	0.592	9.11	0.0244	228.2	0.0376

Solubility of CO_2 and O_2 as a function of temperature. Table 3

For reference to ppm and mole conversions of CO_2: CO2 1 mmol/l = 44 mg / l. The incorporation of $CO_{2\,(gas)}$ into a solution comprise two reactions:

The solubilization CO_2 (gas) → CO_2 (aq)

and the hydration CO_2 (aq) + H_2O → H_2CO_3, K = 2 x 10^{-3}.

Partial pressure is the mole fraction multiplied by the total pressure. For example, at sea level, where the atmospheric pressure is about 10^5 Pa, the partial pressure of oxygen is 2.1×10^4 Pa (21% × 10^5), and the partial pressure of CO_2 is 36 Pa (360 ppm = 0.036%; 0.036% × 10^5 = 36). At the top of a 1500 m mountain, where the atmospheric pressure is about 8.5×10^4 Pa, the partial pressure of oxygen is 1.8×10^4 Pa and that of CO_2 is 30.6 Pa. This is the reason that it is harder for people to breathe and for leaves to photosynthesize at higher altitudes.

"As the buffering effect is overcome, a continued increase in CO2 lowers pH because more carbonic acid is formed…."

Continued on page 9

Dissolved Inorganic Carbon (DIC)

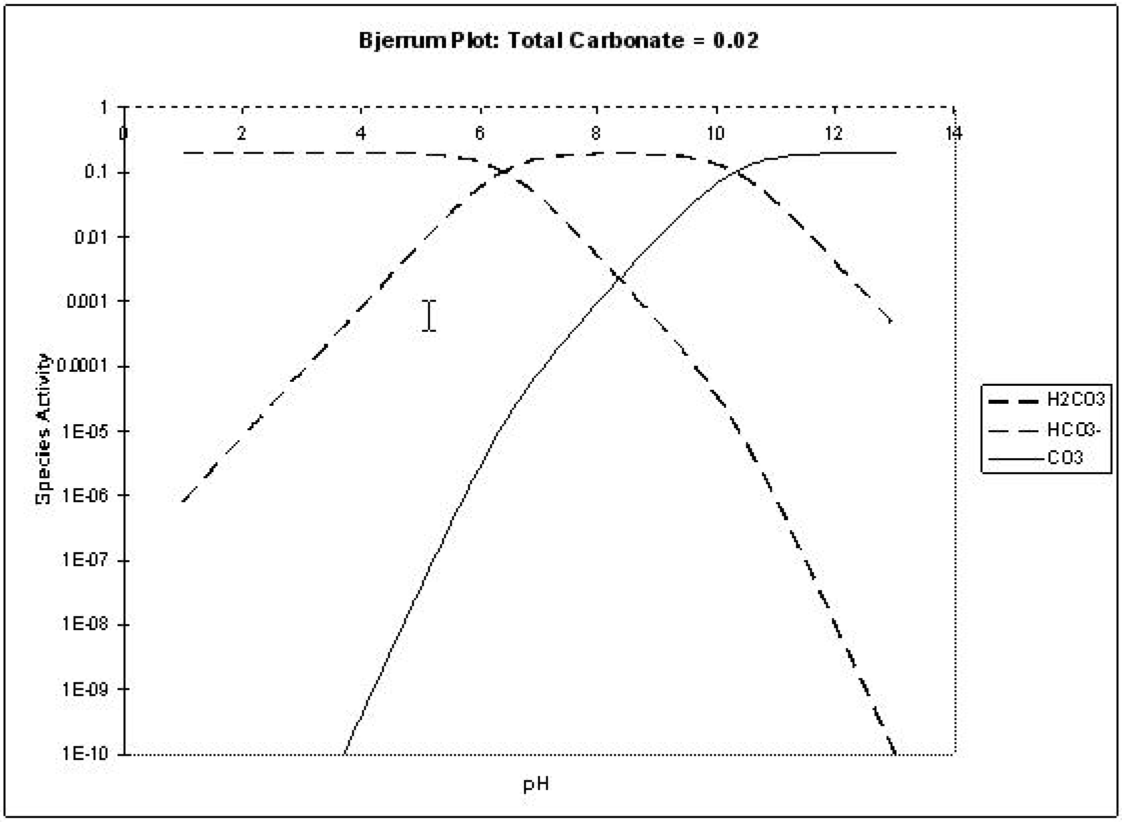

Figure 3

The Bjerrum plot shows the relative ratios of the various species of DIC at different pH's. H_2CO_3 is assumed to be free CO_2. Losses and additions of CO_2 from either photosynthesis and respiration or enrichment will change the pH of the water column. However, the carbonate species as well as other ions dissolved in the water act as buffers and pH changes will be resisted as long as the buffering compounds are not used up. As the buffering effect is overcome, a continued increase in CO2 lowers pH because more carbonic acid is formed. Correspondingly, as CO_2 is depleted, pH rise and are inversely proportional.

Depletion and Primary Production

Free CO_2 is the "species of choice" used by microphytes (algae) and SAMs. Many aquatic plants and mosses can only utilize free CO_2 as a carbon source. However, some plants can utilize bicarbonate (HCO3-) in situations where free CO_2 is low and bicarbonate is abundant. Many microphytes that are adapted to grow in low-light conditions (*Oscillatoria*) can stay alive in the absence of light if conditions are relatively bacteria-free by utilizing organic compounds (glucose) as a carbon source much as do respiring organisms. These organisms are said to be photoheterotrophic. Carbon utilization by this route is at much lower levels in these organisms compared with normal photosynthesis. This maybe a reason as to why *Oscillatoria* blooms occur when the filters are not cleaned regularly.

Continued on page 10

Dissolved Inorganic Carbon (DIC)

Marl Formation

If sufficient loss of CO_2 occurs, such as during periods of high CO_2 uptake in a high light planted aquarium, chemical equilibrium between the carbonate species is lost and insoluble calcium carbonate or marl precipitates:

$Ca(HCO_3^-) \rightarrow CaCO_3 + H_2O + CO_2$

This reaction continues until equilibrium is reestablished. Often other substances will co-precipitate with the marl such as phosphate a limiting nutrient in primary production. As these substances precipitate, they sink out of the photic zone and primary productivity may be adversely affected.

Alkalinity

Alkalinity (also carbonate alkalinity, alkaline reserve, titratable base, or acid-binding capacity) has little to do with how alkaline water is. Rather, it refers to the quantity and kinds of compounds present in natural waters that act as buffers. It is a measure of the buffering capacity of natural waters. These substances are important as most aquatic organisms are sensitive to pH changes. The term alkalinity comes from the fact that these compounds, mostly the carbonate species, collectively shift the pH to the alkaline side of the pH scale. Alkalinity is measured as equivalents of carbonate or bicarbonate. This term also has little to do with hardness, waters may be very soft (low hardness) yet have high alkalinity. Another way to consider alkalinity is as the acid neutralizing capacity (ANC), which refers to the capacity to neutralize strong acids such as HCl, H_2SO_4, and HNO_3. In other words, alkalinity is the ability of an aquatic system to accept protons (H^+).

Borate (H_4BO^-, mostly in sea water and desert lakes)
Humic and Fulvic Acids (in bog environments)
Phosphate species (PO_4^{-3}, HPO_4^{-2}, H_2PO^-)
Arsenates (AsO_4^{-2})
Silicates
Aluminates

Other Contributors to Alkalinity

Table 4

Table 4 discusses several other components that influence alkalinity besides bicarbonates and carbonates. Other factors that will influence and lower alkalinity: seasonal and diel variations in alkalinity (as alkalinity is determined mainly by carbonates and bicarbonates) and seasonal depletions of these species such as marl precipitation. As with the CO_2 species, these situations are seen mainly in highly productive lakes and the littoral zones. *Potamogeton* species often form marl in aquariums due to this bicarbonate usage forming a visible white crust.

Continued on page 11

Dissolved Inorganic Carbon (DIC)

Plant adaptations

Species adapted to high light intensity are called shade intolerant. Those adapted to shade environments are called shade tolerant (most SAMs fall into this group). Shade tolerant species show little difference in their survival and growth rates under shaded or sun. Shade intolerant species were, however, greatly impaired when growing in shaded conditions. This is due to the difference in light compensation point between and carbon allocation between the two species: Shade tolerant plants can maintain a positive carbon uptake under limited light. Shade intolerant plants continue high rate of photosynthesis under low light intensity thus affecting their ability to survive, due to a deficit in carbon uptake. When ample CO_2 is present less carbon is lost and less uptake takes place resulting in a lower compensation point. In general, leaves grown in reduced light tend to be larger and thinner than those grown in full light. Changes in carbon allocation also occur, e.g. decrease ration of root mass to leaf area. These morphological changes increase the chances to capture light, the limiting factor with respect to light.

Responses to UV radiation.

Laboratory experiments show that UV-B radiation can damage DNA, partially inhibit photosynthesis, alter the growth form of plants, and reduce yield (Tevini et al., 1990, 1991a; Mark, 1992). Plants defend themselves against UV damage by having anthocyanins, colorless flavonoids and other phenols that absorb UV-B radiation **but transmit PAR** to the interior of the leaf. It should be noted that these flavonoids are an antiherviory agent as well and tend to be highest in the apical growing tips (the most nutritious portion of the SAM). There is debate as to why these secondary compounds are present in plants and there are likely multiple and separate reasons that provide advantages to SAMs. For example, many red anthocyanin rich plants are found in the understory of tropical rainforest where the light levels are very low and herbivory pressure is high. Growing tips of many plant species also possess high concentrations of anthocyanins which are rich in carbon and possess no nitrogen (often a limiting nutrient) and low Chlorophyll (rich in Nitrogen). Therefore adding stable carbon levels allows a SAM to produce ample anthocyanins which yield red color even at low light intensities. Reducing nitrogen levels will also allow the red color from anthocyanins to appear more but care must be given to not reduce the nitrogen levels since the rubisco which fixes the CO_2 is also a major role player in production of the anthocyanin subunits.

Problems with CO_2 measurements and practical matters with enrichment

Supplying adequate CO_2 or carbon to prevent limitation is a goal of many aquarium plant hobbyists.

Stray current can cause measurement problems, such as those from lighting ballast and submersed pumps. Turning off all electrical components when using an electronic pH monitor or pen is a wise approach here. Stray current can give false positives with respect to CO_2, showing that there is more CO_2 than is really present. While many assume that pH controllers will make the system more stable, often times due to things such as variations in tap water alkalinity and electrical current, they can also cause problems when other changes occur that influence the CO_2 level. Compounding the measurement problems associated with CO_2 are

Dissolved Inorganic Carbon (DIC)

large differences between most alkalinity test kits (the KH test kits) in their wide 17.9ppm per degree units. Some test kits measure in degree units while some measure ppm. The more accurate the alkalinity test kit, the better the final measurement. Utilizing a chemical test kit for pH that has a narrow range can be useful and satisfactory for most cases but more precise electronic meters will provide more accurate CO_2 measurements when used properly.

There is no practical need for adding CO_2 gas at night, microphytes and macrophytes do not use CO_2 at night, only a very few CAM plants can do this. Some arguments exist with respect to pH fluctuations and additions of CO_2 at night to maintain pH. Performing large water changes frequently also changes the pH dramatically yet the organisms respond well to this, the main difference is the amount of gas between the tap source water and the aquarium's water. pH changes can cause problems with livestock health due to other factor other than CO_2 levels which have been traditionally view as a waste product (and something to keep as low as possible) by fish aquarist not keeping SAMs. Long term chronic levels of CO_2 may build up in the aquarium without turning off the CO_2 at night when it's not needed which can arguably do more harm than pH variations. In natural systems with high SAM densities, large pH fluxes occur daily and animals are present without harmful effects. The higher O_2 levels appear the issue in terms of animal livestock health rather than pH nor CO2 levels under practical usage. Therefore, allowing the aquarium to off gas the excess CO_2 at night allows fewer maintenance problems and an increased margin of safety. It also allows higher levels of CO_2 during the photoperiod when the CO_2 is needed without impacting animal health with long term **chronic** high CO2 concentrations when the O2 levels are at their lowest at night.

Some species of algae, namely a red alga, *Audouinella* appear when the CO_2 level is low or variable. Adding more CO_2 will stop their growth and these make good indicators of poor CO_2 levels even if the testing method appears to show adequate CO_2 concentrations. Therefore adding more CO_2 gas will help eliminate new growth. This should be done slowly and carefully and noting the animal's response. *Riccia* is also a good indicator of good CO_2 levels when pearls of O_2 bubble appear roughly 2-6 hours into the photoperiod. CO_2 should be checked often and the aquarist should not become complacent even if they are well experienced and considered advanced. While testing is one method of monitoring, noting the plant's health and looking for signs of algae of a lull in the growth rates are often good signs that something is slowing plant growth and the environmental conditions should be checked. While many have assumed excess nutrients causes algae in the past, the reverse appears to be the case due to the differences between SAM's and microphytes (algae) ecologically in their respective niches. Therefore adding more CO_2 often addresses any limitations with respect to the SAMs and DIC.

Why add so much CO_2 only during the day?

If the CO_2 is kept stable, the plants will catch up, but most aquarist that have CO_2 issues also have CO_2 stability issues. By adding enough CO_2 to reach the **maximum saturation level for plants** (say 25-35ppm) at a high level of light irradiance, the target is much wider to hit for aquarist than say keeping the CO_2 at 8ppm constantly. That is much more difficult but overall, the plants will do well if the CO_2 is stable. For example: A target of CO_2 is 25-35 ppm, that gives you a + or - 10 ppm target to hit versus a target of + or - 1ppm with the 8ppm. Less light places less demand on CO_2 so reducing the light is an effective means of providing more stability in terms of all nutrients including CO_2. Most SAMs fully saturate their rubisco and their production pathway at 30ppm of CO2 (Van et al 1976)

Dissolved Inorganic Carbon (DIC)

CO2 added to excess levels:

CO_2 (like PO_4, NO_3, Fe) dosing recommendations often suggested assumes that excess levels of nutrients will not cause algae. Yes, the aquarist can get away with less than this certainly and this is *easier to achieve with less light*. CO_2 dosing at high levels is no different than adding 1-2ppm of PO_4 versus maintaining a close tolerance between 0.1ppm and 0.2ppm. Both are SAM and microphyte nutrients. Which would be easier to maintain and dose on a practical level? This concept is supported with the Estimative index : http://www.barrreport.com/forums/showthread.php?t=1 and applies to CO_2 as well as PO_4 or other nutrients. Aquarists have traditionally made this target so small that achieving the balance has been very difficult for many/most. As the skills of an aquarist improve, they can reduce the level of nutrients or CO_2 as they chose but it offers little practical use in terms of horticulture. Many have suggested adding **barely just enough** to provide for plant growth. Why place a self imposed hardship or barrier in the way when it's not needed?

Other's have suggested adding just enough nutrients for the plants for specific tanks as the nutrients are consumed, while possible and relatively easy, it requires more testing and management and given the wide range above the minimal need and variations in CO_2 measurements and light measurements, it is more arguable that the two main inputs into plant growth (light and CO_2) should also be closely controlled if that is the conceptual goal. Taking this concept further, adding barely enough light would seem the most prudent if limitation is the goal or not adding CO_2 at all, since SAMs can and do grow well enrichment. Light and CO2 are far more **significant components** to SAM growth than say PO_4. Without addressing these major players in SAM growth, these routines ignore the primary components and focus on relatively minor constituents. Less light at these concentrations will provide more stability and still not cause algae, as algae prefers CO_2 like plants. It's much more an issue of **stable levels** of nutrients or adding enough to fully saturate the nutrients for the plant's needs for any commonly used light level in planted aquariums. The aquarist can choose add just enough or they can add to a wider excess level. The target becomes more and more difficult to hit as it gets closer to the threshold of limitation. Non CO_2 tanks possess less light and do not dose CO_2. They also are more stable than CO_2 enriched aquariums and need virtually no resetting, water changes and no testing due to this stability. The issue of stability becomes an issue when nutrients become low enough to become limiting. Fortunately, SAM's ranges are very wide allowing the aquarist to dose easily without such careful management. When SAMs are provided with stable DIC levels, they adapt quite well and grow successfully.

Further reading of the role of CO2 enrichment and cycling is provided for a basic overview:

http://www.csd.net/~cgadd/aqua/art_plant_co2chart.htm

http://www.brainyday.com/jared/aquarium/discus/co2.htm

http://www.thekrib.com/Plants/CO2/

http://www.floridadriftwood.com/whyCo2.htm

Dissolved Inorganic Carbon (DIC)

Summary

- Difference between organic and inorganic carbon
- Role and types of DIC
- Photosynthetic processes
- Photorespiration and CO_2 and O_2 differences
- Partial pressures
- Bjerrum plot for DIC species
- Depletion and primary production
- Marl formation
- Alkalinity
- Response to UV radiation
- Problems with CO2 measurements and practical matters with enrichment

Note: Next Month's Barr Report will focus on the organic carbon fraction.

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