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Barr Report

# Barr Report

with Tom Barr, Greg Watson, and the Plant Guru Team

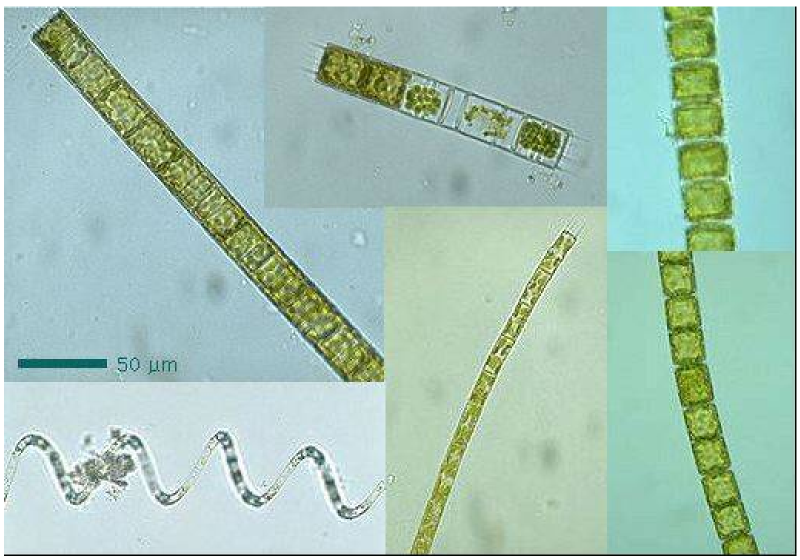
## Diatoms (Bacillariophyta) and Aquatic Macrophytes

### Special points of interest:

- Diatoms are present in all tanks—they are just not as visible except in large numbers.
- Diatoms make up about 1/4 of the entire planets biomass.
- Diatoms appear as yellow-green or yellow-brown algae.
- Diatoms produce about 30% of the planet's oxygen ....

### Inside this issue:






*Melosira* is a very common chain forming filamentous species. Figure 1

*"… Diatoms rarely become a nuisance .. although there are over 10,000 names species of diatoms … they are just not as visible to the naked eye except in large numbers."*

**Introduction:**

Diatoms rarely become nuisances in freshwater planted aquariums or marine planted systems. They are generally present at noxious levels in newly set up aquariums as brown films typically on the glass walls. At very intense light levels (e.g. full sunlight), they may slough off leaves and form a layer on the substrate where current is reduced. Most solutions involved cleaning them off glass and/or adding *Otocinculus* catfish that appear to relish these algae. Generally the diatom bloom occurs for about 2-3 weeks. After this time frame, they subside and are less troublesome from then on. While it might be said this is the end of their presence, nothing could be farther from the truth. They are ubiquitous in any planted tank. They are just not as visible to the naked eye except in larger numbers. They are also found on most other species of algae growing in aquariums as well such as on *Cladophora* and other green algae. They are important for the aquatic ecology and physiology. They have unique life histories, shell formation and composition, reproduction and nutrient needs. The term "Diatom" from the Greek, means "to split in two" and belong to the Bacillariophyta or "stick plants". There are more than 10,000 living diatom species are known, with about the same number of named fossil forms. The extent of the various species may well exceed 100,000 (Round and Crawford, 1990). There are more

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... Diatoms supply about 30% of the plant's oxygen supply ....

# Diatoms and Aquatic Plants

than 500 species commonly recorded from the phytoplankton, periphyton, and surface muds of ponds and lakes thus taxonomy can be a long process. A question that might be posed: why so many species in smaller freshwater systems?

Each species within an algal community has its particular ecological requirements and tolerances. Consequently, algal species tend to segregate along gradients in *time and space*, according to varying patterns of environmental resources, and of biological interactions, such as competition and predation. For example, during the growing season there is a time-series of varying abundances of phytoplankton species in open-water habitat. At certain times, particular species or closely related groups of species are abundant, but then these may decline and other species of phytoplankton become dominant. This temporal dynamic is not totally predictable; it may vary significantly from year to year. The reasons for these patterns in the abundances and productivity of algal species are not understood, but they are likely associated with differences in their requirements for nutrients (NH4, PO4, Si, lack of bacteria etc) and other environmental factors, and perhaps with differing competitive abilities under resource-constrained conditions. Our aquariums are far more stable, thus provides less opportunity for many of these other species to appear unless we destabilize the system. Habitat is also another consideration, many species live in the mud layers, while others in the open water, and yet others live on aquatic macrophytes and other algae as epiphytes. In aquariums, we may isolate and address such unknowns as the aquarists has control over the entire environment allowing them to investigate these cues that Diatoms use to bloom. *Acanthoceras* (phytoplankton), *Aulacoseira, Cyclotella, Fragilaria, Gomphonema, Melosira, Tabellaria, and Urosolenia* (phytoplankton) are some of the more common genera in tropical regions.

*" diatoms can grow to such numbers that submerged plants can have the appearance of being covered with a brown mud— sometimes in very high light tanks, this can be seen and is often mistaken for detritus..."*

A typical cluster of diatoms attached to a cotton fiber. Plant leaves are typically covered with these and *Tabellaria* (below)

... Diatoms' oil-rich, silca-shelled bodies sinking to the ocean floor over long periods of time have been transformed into the petroleum deposits of the world ....



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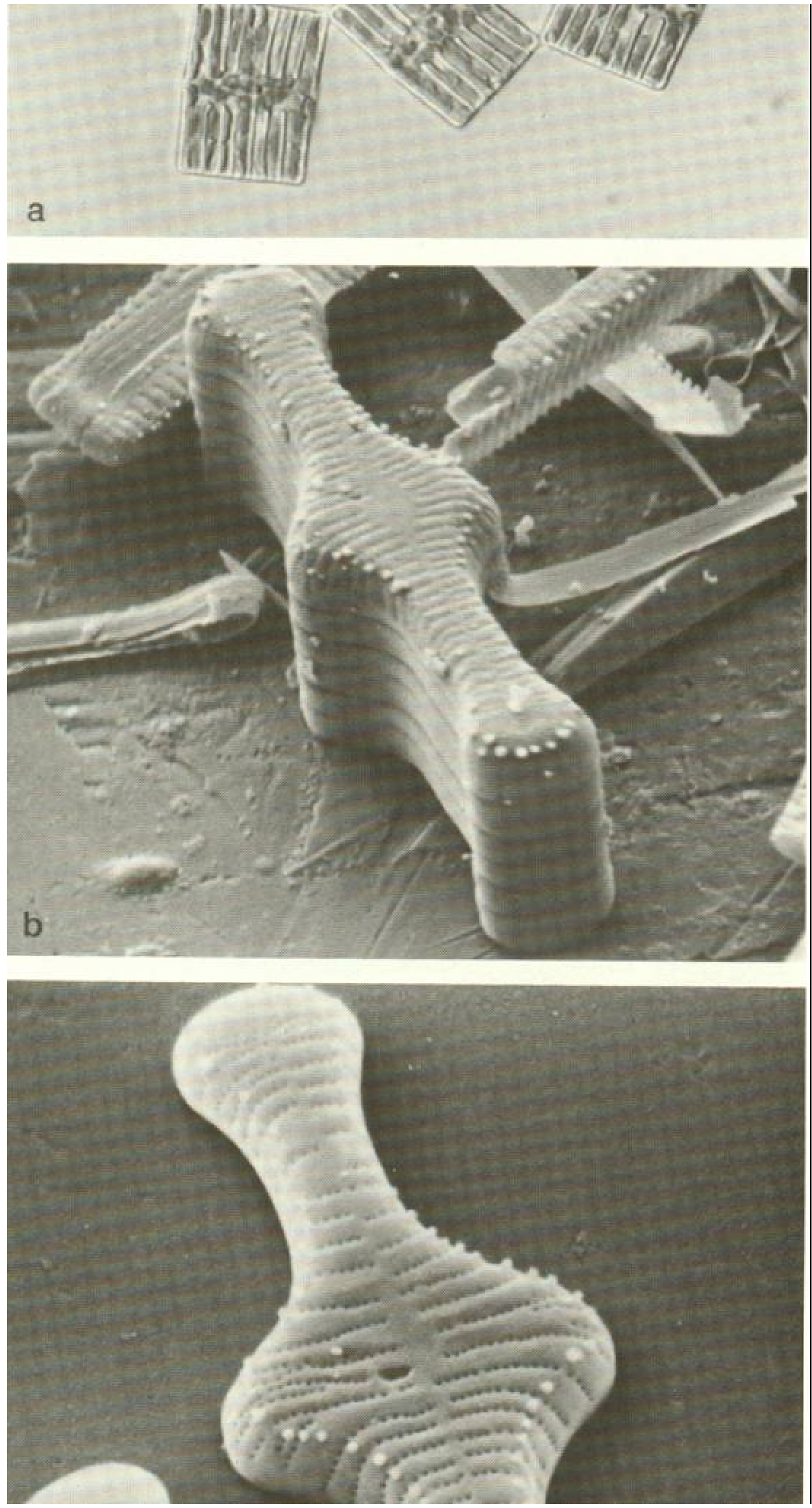
# Diatoms and Aquatic Plants

**Importance ecologically**

Diatoms make up about a quarter of the entire planet's biomass and thus are perhaps one the most dominate life forms to the biosphere. They are extremely abundant in the upper layers of the world's oceans, providing food and nutrition for everything from bacteria to baleen whales. Diatoms supply about 30% of the planet's oxygen supply with the remaining species of algae adding about 40-50%, thus roughly 75% (terrestrial plants/algae supply the remainder). Most diatoms are much less than half a millimeter in size, but their oil-rich, silica-shelled bodies (SiO2), sinking to the ocean floor in vast numbers over long periods of time have been transformed into the petroleum deposits of the world, and their skeletons have formed thick strata of diatomaceous earth which has found application in human products as varied as dynamite, (in earlier times) toothpaste and of course filtration. Whilst most diatoms are to be found in the oceans, they are also abundant and important in freshwater habitats and in moist soil. They are even found growing on bottom of quartz in the hottest places on earth such as Death Valley, California, USA. The EPA uses diatom Biological indicator species for determination of polluted streams (EPA, 2007). They are ubiquitous, there are many species, they are easy to preserve (their "valves" are hard glass) and identify relative to other algae species. It is possible to do the same in aquariums as well, but would require extensive work to answer simple questions better left to a water change and good general maintenance and care. Domic acid production (from marine species) that may cause shellfish poisoning in humans is not produced by freshwater diatoms. Several aquarist postulated that domic acid production may have caused health issues for their fauna and flora. However, given that the freshwater diatoms do not produce it, it's extremely unlikely.

There is also a model that suggest that cloud formation, thus climate as a whole is also regulated by diatoms (Malin and Krust, 1997). Through a secretion of DMS (Dimethyl sulfide), cloud nucleation droplets are formed. Thus with more light: more DMS is produced by primarily diatoms, which increase cloud cover, which in turn, regulates light for a feedback for cloud coverage over the entire planet. Algae thus control cloud formation that controls temperature, precipitation and light. It takes awhile, but there is evidence it does occur. See model below. How might this affect and influence global warming? How might runoff and effluents into the oceans influence this? These are big questions for such a small little alga.




Aquatic plants are rapidly colonized by these algae. While few aquarist see them at the macro scale, they are very common and always present in aquariums. Most samples of leaves older than 1-2 weeks will have colonies. Zemba and Hopson (1996) showed that simply swirling an aquatic plant leaf in a flask for 45 seconds removed roughly 90% of these epiphytes. This might suggest that a good weekly fluffing and swirling the plants, essentially brushing them clean may be helpful. Even if you do not see these algae, they are still there and can cause reduced plant growth by reducing CO2, nutrients and light uptake for the plants. Figure 2

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# Diatoms and Aquatic Plants

*"… Diatoms appear as yellow-green or yellow-brown algae … can also produce long brownish colored filaments in aquariums that are neglected …"*

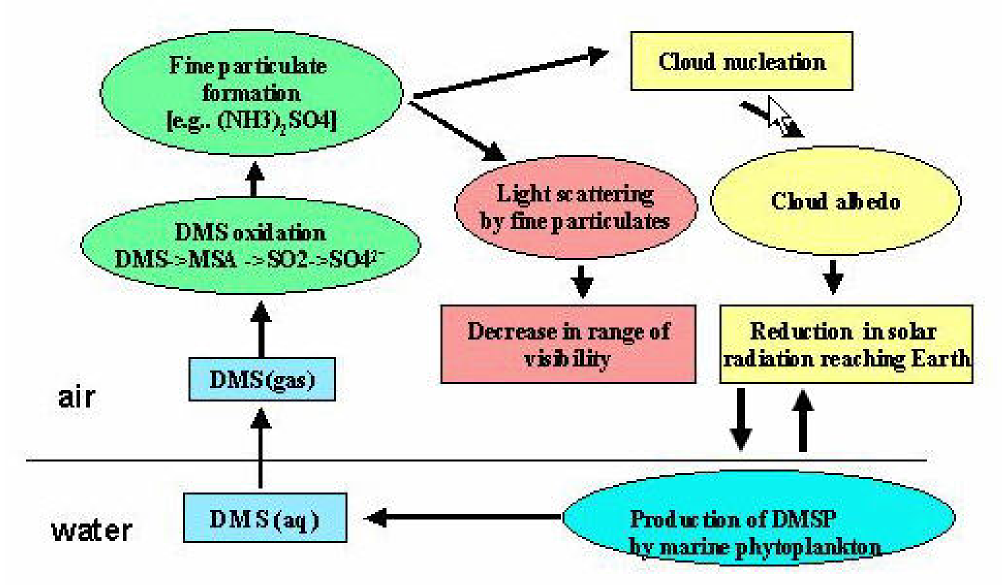
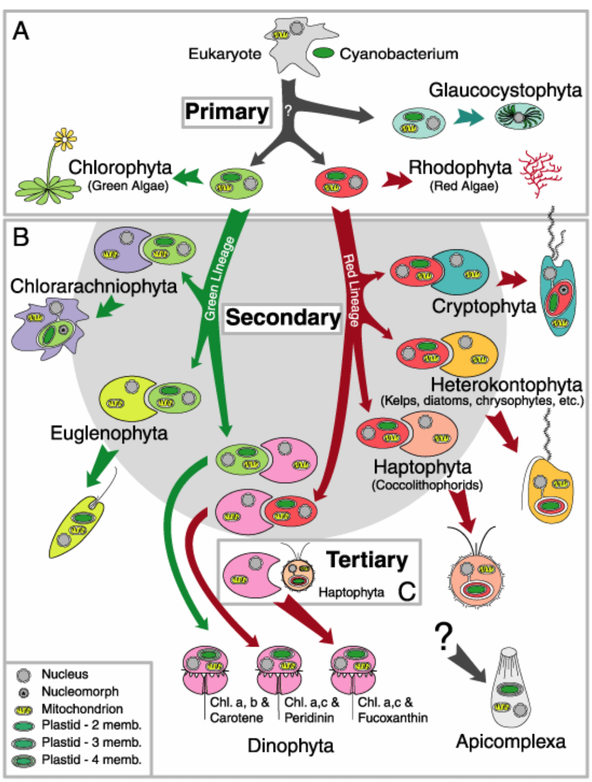



**Figure 3**

## Structure and physiology




Modified from Delwiche, C.F. 1999. Tracing the thread of plastid diversity through the tapestry of life. Am. Nat. 154:S164-S177.

**Figure 4**

The biogenic silica that the cell wall is composed of is synthesized endogenously by the polymerization of silic acid monomers. These monomers are then extruded to the cell exterior and added to the wall. The siliceous skeleton common to all varieties is frequently described as structured like a pill box or Petri dish, and offers two possible views -- the valve view (as in viewing a Petri dish from the top) and the side or girdle view. The two sides are called the epitheca and hypotheca, with the epitheca being on the "inside". They present a great variety of shapes (mostly symmetrical and very attractive) in valve view, but most commonly are rectangular in girdle view. In general terms, the shape of the valve can be described as pennate (elongated) or centric (circular). The shape and markings of the valve are the means by which species are identified. The cell walls of golden-brown algae and diatoms are made of cellulose and pectic materials, a type of hemicellulose. The photosynthetic pigments of these algae are chlorophylls *a* and *c*, and the accessory pigments are carotenoids and xanthophylls, including a specialized pigment known as fucoxanthin. They possess a storage product called leucosin that can be stored as oil droplets (this allows them buoyancy; think about oil floating on the water's surface, they have those heavy glass shells to suspend! Some species actively regulate their buoyancy with intracellular lipids to counter sinking). The general consensus at the writing of this article is that the Eukaryotes arose from the symbiotic union of various Prokayotes, so that chloroplasts, for example, were probably once some sort of little round Cyanobacteria that found it convenient to take up residence inside some larger Prokaryotic cells. Their yellowish-brown chloroplasts typically possess three membranes, suggesting one or several endosymbiotic events in evolution after the first event with a cyanobacteria. Diatoms usually lack flagella, but they are present in gametes.



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# Diatoms and Aquatic Plants

**Life history:**

Diatoms appear as yellow-green or yellow-brown algae that occur singly or more rarely in colonies. *Melosira* may form long filaments in fresh water planted aquariums. Other genera can also produce long brownish colored filaments in aquariums that are neglected. They tend to be more problematic in marine systems however. While PO4 can cause issues for marine diatom blooms, dosing PO4 does not appear to increase diatom biomass significantly; however, species composition may change dramatically. Diatoms reproduce through cellular division and also sexually. Each time an existing diatom divides, the silica valves become smaller. Over time, the individual cells of a diatom population become progressively reduced. Obviously this has a limit. Thus their sexually produced offspring are able to secrete entirely new cell walls. Thus they must go through a phase of sexual reproduction to continue to reproduce new biomass.

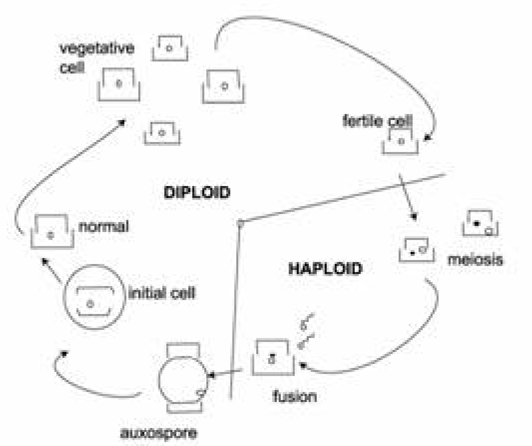


Diagram showing simplified life cycle of a typical diatom. The decrease in the average cell size of a diatom population requires at a certain point the restoration of cell size by the production of an auxospore in which the cell sheds its siliceous frustule. The resulting organic walled cell then produces a new maximal sized frustule within itself. The new first cell may differ from the normal vegetative cell in girdle straucture, valve outline and process pattern.

**Figure 5. Diatom life cycle. It is also plausible that in aquariums, the vegetative life cycle is only present and that NH4 or other inducing factors may be required to induce the sexual stages. It is likely that many algae spores and vegetative reproduction center on such cycling. Thus when a strong inducing parameter or combination of parameters occurs, the algae bloom appears. Once they go through their sexual stages, they are very resistant and much effort will be required to beat the new algae back. Thus a new tank may induce the diatoms, but after several repeated rounds of vegetative reproduction, they no longer can reproduce and conditions do not allow for inducement of the sexual stage. Therefore the diatoms may die out after 2-4 week's time.**

**Silica, a potential limiting nutrient in aquariums?**

Marine diatoms tend to have an order of magnitude less silica than their freshwater counter parts. They also tend to live in more limiting conditions than freshwater species (Conley *et al*, 1989). Their Si: C molar ratios tend to be different thus applying broad ratios from marine to freshwater systems is not suggested. Several aquarists often have assumed, as have many marine aquarists, that limiting Si is a method to control diatom algae. While true in very nutrient poor open ocean systems far from land based nutrient sources, the levels required are extremely low for Si for freshwater as well (Kilham, 1971). Fish waste and many other sources for Si are present as well as endogenous plant sources. Most freshwaters are rich in Si and this limiting nutrients may be added to investigate a causal effect for diatom blooms. As most aquariums use tap water and the paucity of diatom bloom observations in established planted aquariums, would imply that there is little supporting evidence that Si limitation is playing a strong role in their control, rather, another environmental condition is the key for management. Possible causal agents might be NH4 cycling, new or disturbed aquariums, lower lighting. I have observed a higher frequency of diatoms using NH4 rich sediments than without, while not noxious comparatively speaking; they are present at higher frequencies and numbers with higher NH4 concentrations. Si can be added and note the effects on an otherwise stable system (a control). If no diatom increase is noted when Si is potentially limiting, then Si alone cannot be the cause. Si limitation may be a cause if there is high NH4, lower light, no herbivores and perhaps other parameter differences. This is an example how several limitations and inducements may interact and correlate, but not be causal. Thus some aquarists may see some decline in algae, while others see no effect when their Si levels are high. The same may said for PO4 and PO4 removers for aquariums to limit algae. While from a management perspective, it may or may not work, and often does not, it can solve some cases nonetheless. However, to assume that PO4 or Si limitation is causal could not be correct with such observations alone. Confirmation with a control system must be done to show this. This step is rarely done by aquarists claiming to show support for limitations, they do not investigate the other side of their hypothesis to show if it true or not. Adding to their quagmire, they often lack the control to produce a reference tank to test their hypothesis to begin with. Thus in the hobby, many aquarists make such claims that Si, PO4, NO3 and other possible parameters are the cause for algae growth or decline. This presents problems in addressing the real causal relationships and confuses new aquarists. A goal in the series of the Barr Report newsletter articles is to highlight such methods to address such arguments about testing, correlations, and causation. Historically this has led many aquarists to attempt difficult self imposed management methods that do not focus on growth of the plants. If there is no cause associated



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# Diatoms and Aquatic Plants

with a noxious algal bloom for Si levels, why should the aquarists spend their time attempting to maintain it near 0.0 ppm? While Si is not generally considered a plant nutrient (grasses use Si), others are and this may cause issues for plant growth which requires more nutrients than algae under limiting conditions for virtually every nutrient.

Photograph by R. M. Spechler, U.S. Geological Survey.

**Figure 19.** View toward old springhead at Gemini Springs.

Local natural ponds in Pt Reyes national seashore, Marin County, California.

Diatom bloom in a freshwater stream.

**Elemental composition of freshwater algae:**

Table 1. Elemental composition of algae (from Healey 1973).

| Element | Dry weight (µg mg⁻¹) Avg | Range | Relative atoms |
|---|---|---|---|
| H | 65 | 29–100 | 8,140,000 |
| C | 430 | 175–650 | 4,460,000 |
| O | 275 | 205–330 | 2,120,000 |
| N | 55 | 10–140 | 487,000 |
| Si | 54 | 0–230 | 237,000 |
| K | 17.3 | 1–75 | 55,000 |
| P | 11 | 0.5–33 | 43,800 |
| Na | 6.1 | 0.4–47 | 32,500 |
| Mg | 5.6 | 0.5–75 | 28,700 |
| Ca | 8.7 | 0.0–80 | 27,500 |
| S | 5.9 | 1.5–16 | 23,800 |
| Fe | 5.9 | 0.2–34 | 13,800 |
| Zn | 0.28 | 0.005–1.0 | 540 |
| B | 0.03 | 0.001–0.25 | 350 |
| Cu | 0.10 | 0.006–0.3 | 200 |
| Mn | 0.06 | 0.02–0.24 | 138 |
| Co | 0.06 | 0.0001–0.2 | 125 |
| Mo | 0.0008 | 0.0002–0.001 | 1 |

Table 1 (above) highlights the major elemental constituents of freshwater algae. Surprisingly, Si is very high in this table at 55ppb of dry weight, roughly the same as nitrogen based on weight/mass. Note that relative atoms or atomic ratio versus molar weights are radically different. Be careful not to confuse the two! Many aquarists make this mistake and try to use atomic ratios for their molar weights for dosing. Also note the wide range found in natural systems. Our systems are likely less limiting nutrient wise, so what is preventing their blooms? We may add each of these nutrients and note the effects on a referenced healthy planted aquarium to test such questions.



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# Diatoms and Aquatic Plants

Table 2. Relative elemental composition of algae (normalized on total dissolved P on a molar basis) compared to the relative mean composition of the dissolved constituents of river water and ocean water. Underlined values are similar in abundance to algal requirements (relative to P) or scarcer. Values in parentheses are highly uncertain.

| Element | Relative composition: River* | Algal† | Ocean‡ |
|---|---|---|---|
| H | | 186 | |
| C | 738 | 102 | 1,000 |
| O | | 48 | |
| N | 28 [21]§ | 11.1 | 13 |
| Si | 146 | 96‖ | 43 |
| K | 26 | 1.3 | 4,434 |
| P | 1.0 | 1.0 | 1.0 |
| Na | 169 | 0.74 | 200,000 |
| Mg | 123 | 0.66 | 23,000 |
| Ca | 28 | 0.63 | 4,480 |
| S | 146 | 0.54 | 12,000 |
| Fe | 0.55 | 0.32 | (0.0004) |
| Zn | 0.35 | 0.012 | 0.003 |
| B | 0.13 | 0.008 | 182 |
| Cu | 0.12 | 0.004 | 0.002 |
| Mn | 0.12 | 0.003 | 0.002 |
| Co | 0.003 | 0.003 | (0.00001) |
| Mo | 0.004 | 0.00002 | 0.048 |

* Ratios are calculated from the following sources: Meybeck 1982 for P and N concentrations; Livingstone 1963 for S and C; Martin and Meybeck 1979 for the remaining concentrations.
† Healey 1973.
‡ Broecker and Peng 1982.
§ Bracketed value is based on total dissolved inorganic fixed N and total dissolved inorganic P.
‖ Parsons et al. 1961 and Reynolds 1984; requirement is for diatoms only.

Table 2 looks at marine and river ecosystems for relative concentrations and compares them to that of the algae. Algae have the ability, as do plants, to sequester and concentrate high levels of nutrients from their environment. Thus even at low, but very importantly, steady concentrations, algae can exists and grow well. While the ratios are slightly different, the ability is similar in aquatic macrophytes. The problem with this in aquariums, they are very small relative to rivers and oceans and it is very difficult to maintain a steady low residual state and adding to that, poor test kits and methods compound the issue. The other questions are: is the low range of nutrients really necessary for healthy planted aquariums and healthy fish and fauna? If so, why are these same rigorous criteria not applied to all unplanted systems in the hobby as well? Only P, Fe and Co in river water are potentially limiting, all other elements would be available in excess. The hobbyists may add KH2PO4 and Fe note the effects (again, using a stable system as a reference). When this is done, no blooms occurred in both CO2 and non CO2 enriched systems. Hobbyists should be encouraged to test such hypothesis if they have the reference planted aquariums. Cobalt is rarely discussed and not thought to play a role in limitation in freshwater systems.

### Silicon, nitrogen and phosphorus

Table 5. Optimum Si : P atomic ratios for freshwater diatom species. Relative position is indicated for some species for which absolute values have been left blank because they are yet to be defined (from Kilham and Kilham 1984).

| Si : P | Species |
|---|---|
| | *Synedra filiformis* |
| | *Fragilaria crotonensis* |
| 96–93 | *Asterionella formosa* |
| | *Tabellaria flocculosa* |
| 75 | *Diatoma elongatum* |
| | *Melosira italica* |
| | *Fragilaria capucina* |
| | *Stephanodiscus hantzschii* |
| 6 | *Cyclotella meneghiniana* |
| 1 | *Stephanodiscus minutus* |
| | *Stephanodiscus astraea* |

Table 5 Note the large differences in optimality. By limiting one nutrient, other species may dominate. This may have both good and bad consequences for management however. It depends greatly on which species is problematic and which species is desired (if any).

Table 4. Optimum N : P atomic ratios for some freshwater and marine phytoplankton (from Smith 1982 and Kilham and Kilham 1984).

| N : P | Species |
|---|---|
| 87 | *Scenedesmus quadricauda* |
| 39 | *Cryptomonas erosa* |
| 30 | *Scenedesmus obliquus* |
| 28 | *Oscillatoria agardhii* |
| 25 | *Fragilaria crotonensis* |
| 24 | *Chaetoceros affinis* |
| 23 | *Selenastrum capricornutum* |
| 21 | *Ankistrodesmus falcatus* |
| 21 | *Pseudoanabaena catenata* |
| 12 | *Skeletonema costatum* |
| 12 | *Asterionella formosa* |
| 10 | *Synedra ulna* |
| 9 | *Microcystis* sp. |
| 7 | *Melosira binderana* |

Table 4 shows some wide variations in the N: P ratios of various phytoplankton. Note that many of the diatoms in this list are high for their P ratios relative to N. Diatoms are often highly preferred by herbivores as well.



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# Diatoms and Aquatic Plants

**NH4 or Si or P?**

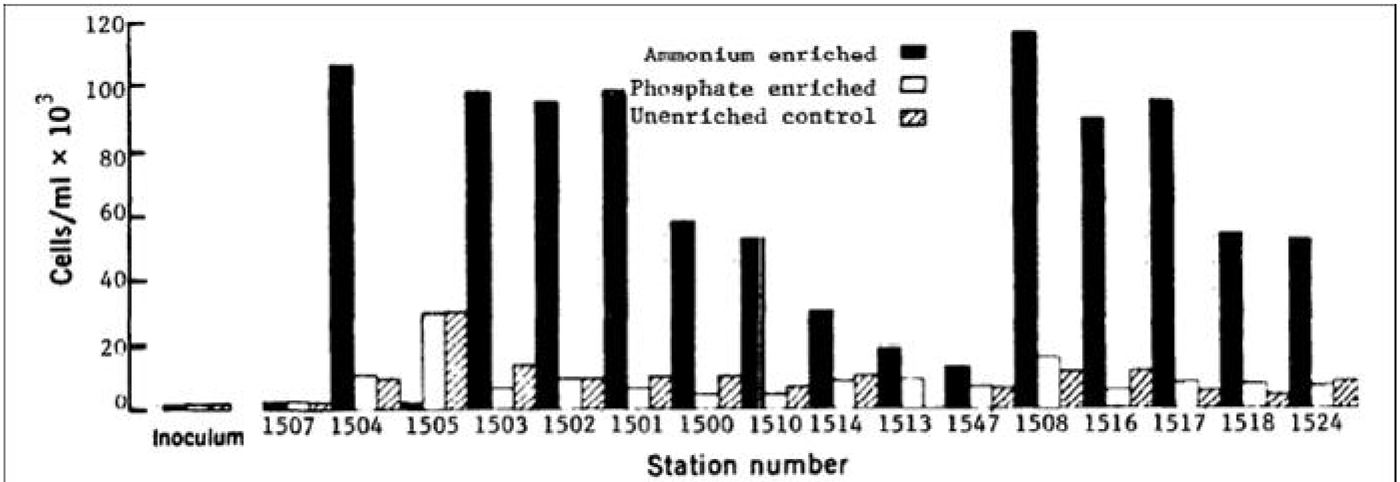


Fig. 9. Growth of *Skeletonema costatum* in unenriched, ammonium-enriched, and phosphate-enriched water from the New York Bight (from Ryther and Dunstan 1971).

This data may suggest that it is NH4, and with a newly set up tank, diatom blooms are a common observation and a lack of biological bacterial cycling of NH4 could lead to this, and the timing of the biological nitrogen cycle also correlates well with the reduction of the diatoms at about the same time, however, this is ***speculation***. PO4 has been implicated in marine planted systems through over dosing of PO4 using KH2PO4 at over 0.5ppm for extended periods by several hobbyists repeatedly.

***Rhoicosphenia curvata***



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# Diatoms and Aquatic Plants

### Rift lakes

Research on algae in the great rift lakes has received some attention (Hecky, et al) in recent years. Production rates are relatively similar between both lakes at 0.8 and 0.7 respectively for area.

Table 12. Parameters related to algal production for Lakes Tanganyika and Malawi (from Hecky and Kling 1987). The flushing rate is calculated as volume divided by outflow.

| | Tanganyika | Malawi |
|---|---|---|
| Flushing rate (yr) | 7,250 | 890 |
| Maximum depth (m) | 1,470 | 785 |
| Euphotic zone (m) | 30 | 50 |
| Perennial thermocline (m) | 150 | 200 |
| Chlorophyll (mg $m^{-3}$) | 1.2 | 0.7 |
| Algal biomass (mg $m^{-3}$) | 150 | 85 |
| Primary production (g C $m^{-2}$ $d^{-1}$) | 0.8 | 0.7 |

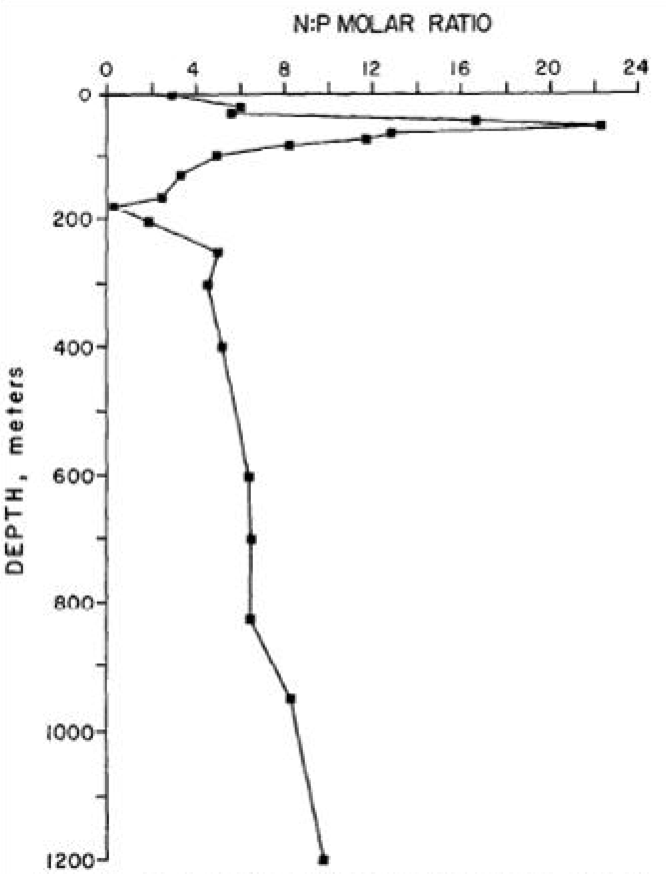


Fig. 15. N : P ratios of dissolved inorganic species at different depths in Lake Tanganyika, April 1975 (data from Coulter 1977).

Phosphorus levels are very high relative to nitrogen in the upper layers and decline rapidly to the limit of the light photic zone, and then rise again to a maximum of 1:1 at 180 meters depth. Wind and upwelling events can bring nutrients up to the photic zone and cause a bloom and this often occurs in many systems. Adding to the complexity, as decaying material from the photic zone sinks, it also contributes to NH4 pools as well. The upper layer of water has rapid recycling of nutrients and only a small fraction may sink out of the photic zone, however over time, this can cause very strong effects and massive pools of nutrients to be imported or exported. Consider this same concept with the substrate in aquariums. What occurs when plants are uprooted and the sediments are disturbed greatly? How might we mitigate the potential negative effects? Generally a large water change will prevent an algae bloom in these cases. While this is a large water column example rather than sediment, similar processes occur in both systems as well as the hobbyists' planted aquarium. Note also, this data does not distinguish between which species of nitrogen such as NO3 versus NH4.

### Concluding remarks:

In the summer waters of a healthy pond, diatoms can grow to such numbers that submerged plants can have the appearance of being covered with a brown mud which the microscope reveals as a dense growth consisting entirely of diatoms. Sometimes in very high light tanks, this can be seen and is often mistaken for detritus. This is common in outdoor lab containers used from macrophytes growth studies. Many common species are almost always present, but few are problematic in the planted aquarium. Si limitation appears to play a very limited role in their control in aquariums. Life histories may also play a strong role. There are many species across very wide ranges and nutrient levels. Herbivores are particularly useful for control in most cases.



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