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Barr Report

Barr Report

with Tom Barr and the Plant Guru Team

Growth Relations of Aquatic Macrophytes Volume 1

Special points of interest:

- Feature Article "Growth Relations of Aquatic Macrophytes Volume 1."
- Factors that affect plant growth
- Light Intensities and period and the roll of growth

Introduction:

How do plants grow? Some may find this a seemingly simple question. Often the best questions are deceptively simple. Growth of macrophytes is defined by the same definitions in terrestrial plants and algae: The progressive *irreversible* development of an organism (Taiz and Zeiger, 1998). Lambers, Chapin and Pons (1998) define growth as increment in plant mass, volume, length and/or area. If a plant takes up water, it may gain mass, it may increase in length, volume, area with no net gain in carbon. So does this definition by Lambers, Chapin and Pons (1998) adequate for aquatic macrophytres and plants in general? Perhaps not by many people. Another set of good simple questions are : what type of growth is being discussed? Root growth? Vegetative growth? Floral growth? Fruit or tuber growth? Stem or leaf growth? In general, aquatic macrophyte growth in the narrow field of aquatic horticulture tends to be almost entirely vegetative for hobbyists and a few species are grown from seeds on rare occasion.

"… Many hobbyist think of growth only in vegetative terms and often then only in terms of the shoot growth and length rather than in biomass and root growth..."

How is it measured? Generally plant growth can be measured quite a number of ways. Dry weight biomass is a very common and simple method. Wet weights are sometimes used (but think about water that sticks to the plant by adhesion) of a plant, would this be a good assumption, or a bad assumption? If the wet/dry weight ratio is stable, then

Water column Ferts? You bet, Seachem has led the way for many years and will continue to do so with a strong commitment to the hobby and to the planted hobbyist.

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... How do Plants grow?
and
how do we measure
growth? ....

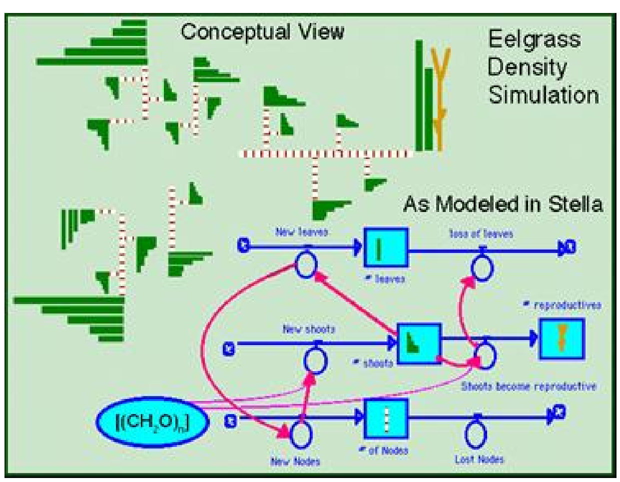
"The Juvenile Growth Phase is characterized by the most rapid rate of growth the plant will undergo ..."

Generally, plant growth can be measured quite a number of ways...
Biomass
Vegatative
Root Growth/Tuber growth

these wet weights can be used, there are methods to address such issues. Cell number is another method at the microscopic scale. Kinematics is a rather interesting method to describe and measure growth (see Silk, 1994). This involves the movement of fluids such as ocean waves produce specific forms, as plant cells are primarily fluids this approach has been used to describe plant meristematic growth.
What about hobbyists? Often the hobbyists has little access to such methods, but more basic methods may be employed even if they have some assumptions that might not be ideal in a more rigorous approach. Simply measuring shoot length over time or new bud formation over time can be quite useful. Wet weights can be used as long as the treatment for each measurement is similar. A salad spinner to remove the water consistently is useful and cheap. Drying the plants for 30 seconds of spinning in the salad spinner is fairly consistent and some researchers have used this method with fairly good results.

This requires accurate scales as do dry weights. One of the biggest problems for the aquarist is the control tank. Most often aquarist do not set aside a control tank, they have little way to know if their test treatment has any real affect compared to a non treated tank. Additionally, the aquarist that might have two similar aquariums often has trouble keeping them in similar shape even without any such treatments. Split tank test work well as the water chemistry is similar between each side, but often the only parameter that is easy to keep isolated is light.

Another general question when approaching growth and other questions concerning plants is providing a good stand in which the aquarist and experimenter might compare treatments against, what is the control in an aquarium? What conditions should be utilized for this standard? In the field for Plant Ecologist, often the natural setting is ideal for this over time and seasons since this is the area of interest for the Field Biologist and how larger scale processes work in natural and perturbed systems. For the plant molecular biologist samples and treatments are often done in the lab. What about for the aquarium setting? The aquarium is somewhat similar to the lab green house settings. We have entire environmental control of the plant's habitat. Thus it is logical to assume that all the needs for "optimal growth" are being met when applying various treatments to see how they might affect growth rates. What is optimal growth? It is the same as "maximum" growth? No, many assume as such, plants can grow for short periods at maximum growth rates but only for short time frames and over time the optimal rates will produce more biomass (quantity) and better quality.



http://www.uvm.edu/giee/GrBay/plant.html
See the model in action!!! Try it out..

Plant growth is often measured as a change in area, length, volume, height, wet or dry weight. These methods may not always be a satisfactory measure of growth at a particular stage of plant development, e.g., a germinating seed or tuber or bulb may show an overall

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loss in dry weight due to the utilization of food reserves during respiration, although the seed is definitely growing as evidenced by its emerging roots and shoots.
The relative growth rate (RGR) which is the size increase per unit interval of time has two components: the net assimilation rate (NAR) and the leaf area ratio (LAR). The NAR is the rate of increase of dry weight per unit time per unit of leaf surface which is a measure of the amount of photosynthetic product going into plant material. The LAR is the ratio of leaf area to dry weight which is the measure of the proportion of the plant that is engaged in photosynthesis. Combined they give a relative description of growth over time based upon plant characteristics.

Vegetative Growth:

A seed is considered germinated when it has produced a plant that is potentially capable of continuous growth. From the beginning of this stage, until initiation of the first flower primordium, the plant is in the vegetative stage of growth. When a plant cannot be made to flower it is said to be juvenile.

The juvenile growth phase is characterized by the most rapid rate of growth the plant will undergo. As well, the juvenile plant may exhibit different morphological or physiological features than a mature plant of the same species. A common feature of many juvenile plants is the ability to initiate adventitious roots readily, an ability which is often decreased or lost in mature plants. The juvenile phase varies from one to two months for annuals, to many years for woody perennials. The ability to influence the length of time a plant is in the juvenile phase is important in some circumstances. Plant propagators want to maintain juvenility in order to vegetatively propagate cuttings while flower and fruit growers want to reduce the juvenile phase. Earlier flowering and fruiting reduces production costs and allows for an earlier return on investments. Environmental factors such as periods of long or short daylight, varying nutritional levels or supplying carbon dioxide enriched atmosphere may increase vegetative growth and if properly controlled may shorten the time to maturity. The affect that environmental and hormonal factors have on the length of juvenile phase will depend ultimately on genetic control.
A plant is considered mature when it becomes potentially capable of reproducing. Although a plant may be mature, flowering may not occur until environmental conditions are favorable (7).

How does the role of CO2 affect plant growth in moderate, high, and excess light conditions ...

The following are factors that affect plant growth

- **Low O2 affects plant growth**
- **Photosynthesis affects plant growth**
- **Light affects plant growth**
- **Respiration affects plant growth**
- **Transpiration affects plant growth; do aquatic plants transport nutrients this way? (See paper Pedersen's paper (1993))**
- **Environment affects plant growth (Water parameters, grazing, pruning)**
- **Temperature affects plant growth (extremes/optima)**

Usually expressed as dry weight (total of the part we're interested in such as grain), height, length and diameter. Growth of an annual plant related to time is an S shaped curve and for one growing season for a perennial plant. Aquatic macrophytes tend to continue the rapid rate of growth and do not level out except when limited by some factor such as pruning, nutrient/light/CO2 limitation (dashed line in figure 1).

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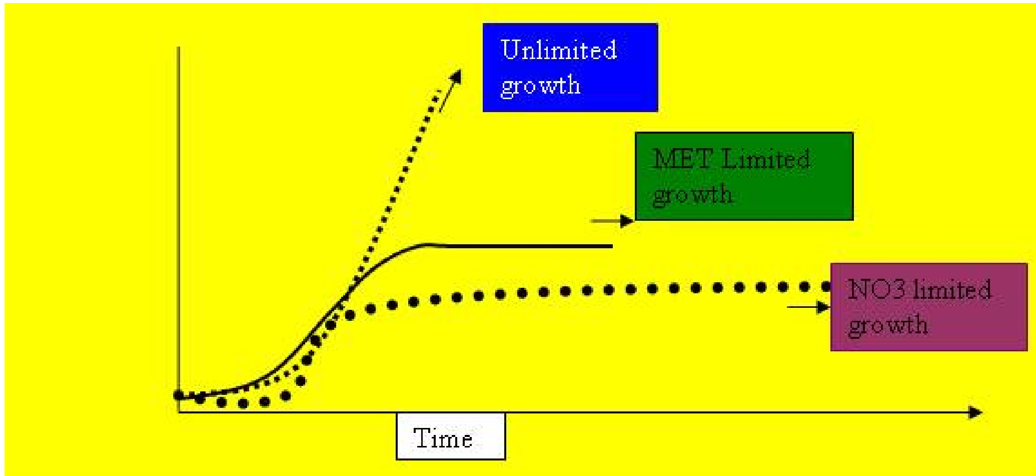
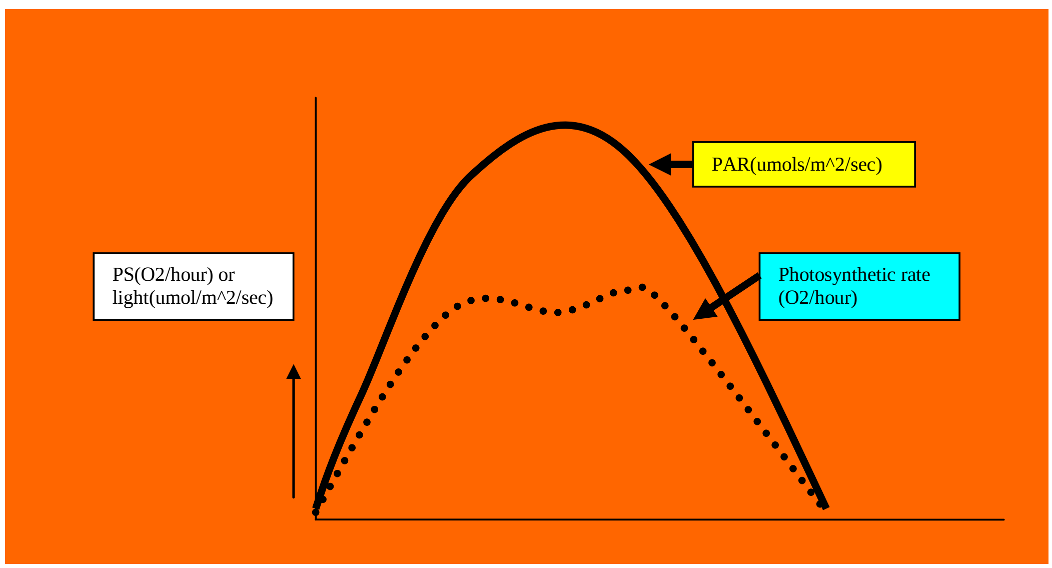
"… As a planted tank matures, the growth in biomass increases and requires the user to respond to it …"

Models:



Figrue 1. All plants have limited growth due to a number of factors. Generally growth is restricted by metabolic (MET) limitations under optimal growth models. The optimal growth rate is then limited from this level downward due to nutrient limitations and environmental stresses.

Growth throughout the day:



6:00 am 12:00 6:00 pm **Figure 2**

Time

Figure 2 shows the midday lull in Photosynthesis (adapted from Jones, Harwick and Eaton, 1996).

Some questions that are not immediately clear from Figure 2:

- Are plants just being lazy or "lollygagging" in the middle of the day?
- Why would they not fully grow at the optimal rates?

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In general, many appear to be limited due to low CO2 at the midday to afternoon time frames. All the CO2 is used up in submersed aquatic macrophytes, in terrestrial systems, low water potentials can also do this as well as photonhibition (Barko *et al*, 1991; Corlett *et al*, 1994; Copertino, et al 2006). Poor underpowered CO2 delivery can produce such curves; it adds enough to take advantage of part of the light, but not all. This is quite common and plants appear not as healthy, they do not thrive to the same degree as other tanks with non limiting CO2 levels. Some species may have smaller miniature growth towards the apical tips as well as stunting. With lower light intensities, such curves begin to follow the radiation levels.

Rhinox diffuser's. I've found there to be very consistent, well made and very good pricing

A typical aquarium with CO2 fertilization with moderate, high light and excess light:

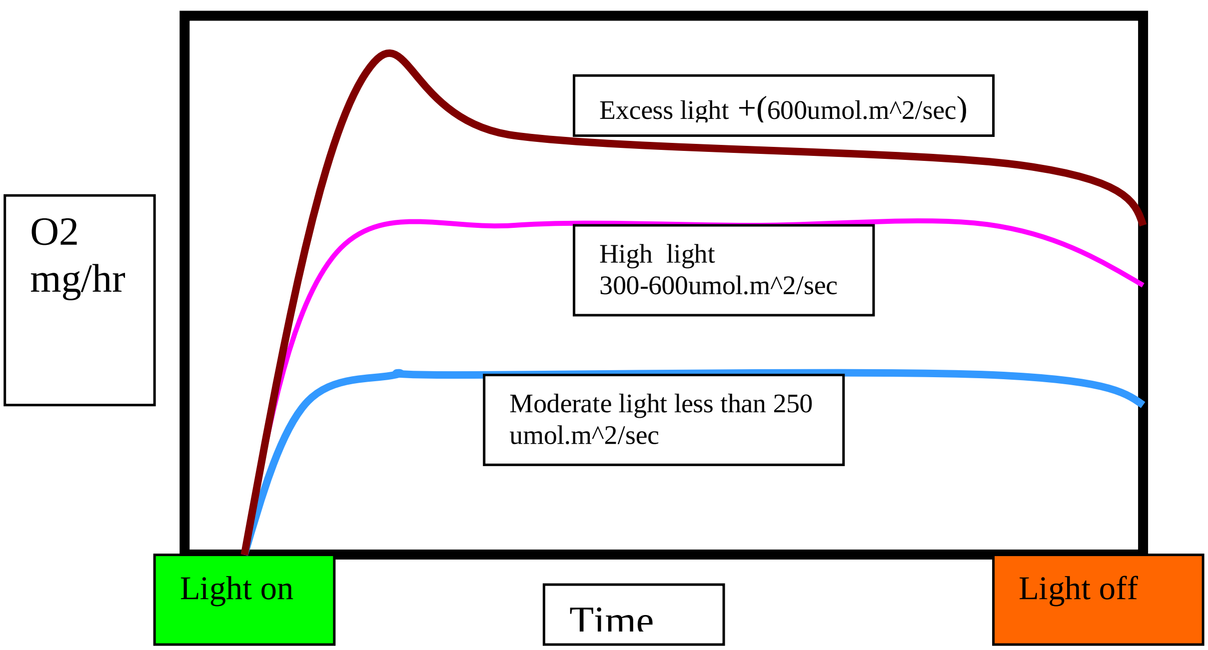

Figure 3 shows a model for three light intensities and the corresponding O2 production due to aquatic plant production. As the lights are turned on, the rate of O2 production rapidly rises. Note what occurs with excess light, there is a rise that exceeds the capacity for "optimal" growth. The plant down regulates this maximum growth rate by this excess light due to metabolic rate limitation in photosystems I and II and the Calvin cycle. Adding more CO2 will not drive the system faster as it becomes a "bottle neck" due to excess light energy. This excess light can destroy the enzymes and chemical pools in PSI and PS II and limit growth if it persists for long time frames. Although a temporary spike in growth may allow for a higher rates for a few minutes, this eventually is down regulated. Note: such models are useful in thinking about what might occur when different environmental factors are added to a system. Aquarist may find such modeling useful and predictive.
Following each line can help explain each level over the day cycle.

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Growth over time:

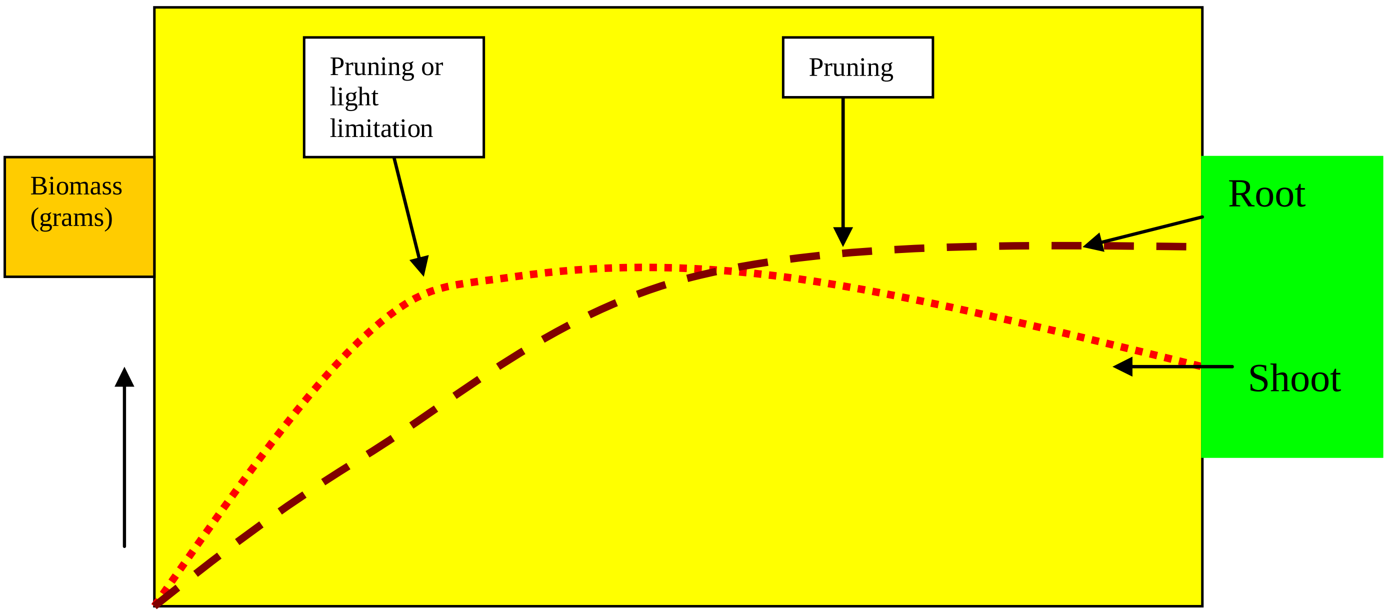

Figure 4. If the aquarist does not prune, the plant biomass increase rate rapidly slows down and becomes light limited. This shading effect reduces the ability for the plants to continue their biomass increase. Also of interest is the change in root and shoot growth, uprooting and pruning roots is an often overlooked component. As the plant biomass increases through time……what occurs with respect to CO2, NO3, K+ demands for the system? Do they increase and correlate with the increase in biomass? Yes!!! Large biomass of aquatic macrophytes is often considered the defense against algae. Not due to removal NO3, PO4 and CO2, but due to light limitations and NH4 limitations as aquarist only add NH4 in the form of fish waste to planted tanks, clearly, a tank with 1 kg of plant biomass will be able to remove NH4 at a much faster rate and have far more capacity to absorb NH4 than a tank with only 0.1 kg of plant biomass. Often aquarists have discussed maturation and long term stability of planted aquariums. Once enough plant biomass exists, then such observations appear to make sense. New tanks therefore will do best and achieve this stable state faster if the starting biomass is high.

In figure 4, if the aquarist does not prune nor add any nutrients, algae will start to grow and plant's lower leaves will decompose and leach out reduced Nitrogen (NH4). Green water will not appear due to the low light, but other forms of algae will appear such as green hair algae forms. In non Carbon enriched systems, such growth is slower, roughly ten times that of a CO2 enriched system. Such slow growth allows much more time before pruning is required and the nutrients are depleted. Additionally, when the plant's upper new leaves begin to shade the older leaves in non CO2/carbon enriched systems, the rate of leaching is greatly reduces as well. This, in effect, allows smaller rates of NH4 production from decomposition of dead leaves. Thus the plants are able to recycle their lower leaves into new growth at the tips to seek light and to outpace algal growth on older leaves. The result is low algae presence whereas the same approach will not work well at growth rates ten times faster using CO2 gas enrichment. Algae respond to high levels of reduced nitrogen such as urea and NH4. Such high levels of NH4 will exist in a neglected CO2 enriched aquarium along combined with low limiting levels of nutrients.

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Lots of fish to go with lots of plants! Note: they are generally smaller tetras.

The keys are responding to this growth and change in biomass through time. As a planted tank matures, the growth biomass increases and requires the user to respond to it.

A simple method is to assume that a system is already at the maximum rate and high light for dosing CO2 and nutrients. Another method is to slowly add more as more plant biomass accumulates and try to follow the uptake rates. This is obviously more difficult to achieve from a management perspective, although less wasteful in terms of fertilizers. The economics of aquarium fertilizers is such that are insignificant for most using KNO3, KH2PO4 and so forth, the real economic factor is typically the trace element mix, such as Tropica Master Grow or SeaChem Flourish, but CMS Plantex+Boron is very cheap, but many feel the brand name traces tend to do better than the CMS+B. A good economic approach is to be wasteful and target higher levels of macro nutrients and address trace additions more critically, unfortunately, testing for trace elements presents serious problems (discussed in the Fe and Mn BarrReport), thus the horticulturalist is left with using the plants to gauge the need for changes in the dosing routines. Such reductions in dosing till the plants respond works quite well for hobbyists. No test kits are needed other than close observations of the macrophytes. Slowly changing the volume of trace elements added each dose can be done and be assumed to be consistent. More so that test measurements of the water column.

An example is adding 5 mls of TMG to an 80 liter tank a three times a week. If the plant biomass is low, try adding 2 mls three times a week and note plant health vs. 5 mls. Give the plants about three weeks before making a decision. Note subtle changes also, coloration, sheen, waxy layers, venation, leaf tips and so forth. Trace elements take sometime before the plants respond negatively, but the same is not true when the plants are limited and you add them back! They have reserves when the concentration of dosing is reduced; they are depleted if the plants are limited. This is an important difference when noting changes in dosing routines, so called “fat plants” have a much longer response time before seeing changes in growth than would “limited” or “starved” plants.

Nature’s own: White bark pine bonsai, about 400 years old and 18 inches tall

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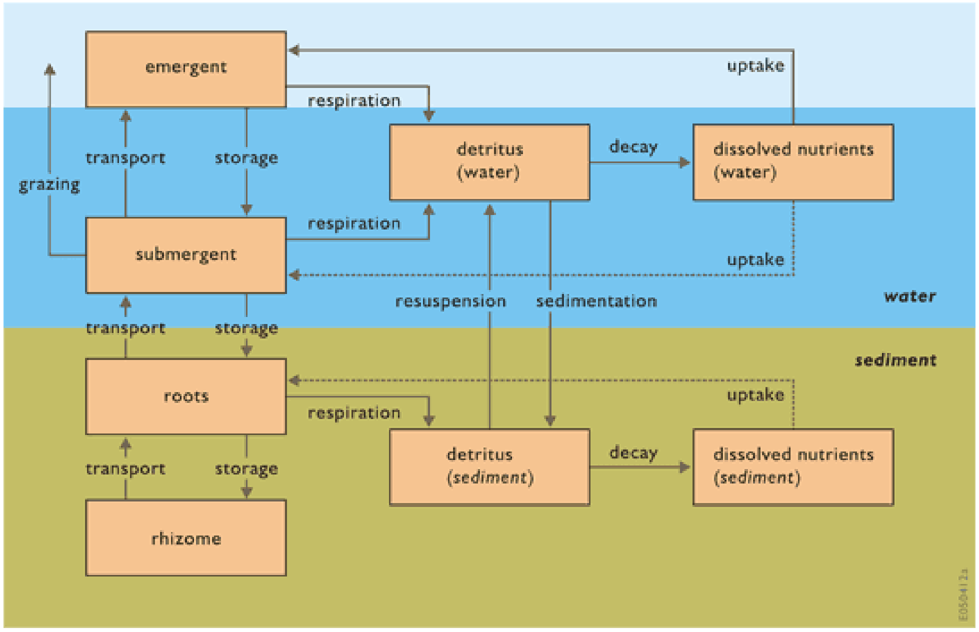

Figure 5
Figure 5 is an over view of macrophyte growth cycling in wetlands. It is useful to look and consider the import and exports of submersed plant biomass. This system evolved without high CO_2 gas and when the rate is increased ten fold, these systems cannot respond as fast. Similarly, modern agriculture must tend the fields and add fertilizers and control weeds and pest to continue to produce crops at such high rates of production.

Measuring growth in aquatic systems:

Numerous studies have debated over what parameters to study for production rates of growth in aquatic systems. Oxygen production from macrophytes and microphytes is a useful parameter and is used and suggested in classic Limnology experiments such as Hutchinson (1975), Wetzel (2001) and Odum (1956). When comparing nutrient enrichment studies and algae and macrophyte production rates, various researchers have used this relationship as well (Wright and McDonnell, 1996). Kemp *et al* suggested that of six methods considered (O_2, ^{14}C, biomass accumulation, DIC incorporation, and bottle exchange) all where relatively effective for submersed plant growth measurements (1986). I have suggested using dissolved O_2 meters for many years for determination of plant growth differences between treatments, few hobbyists measure O_2 production though. There is a greater need for such measurements to better gauge differences between treatments.

Morphological growth differences:

Sediments:
Vallisernia plants grown under low pH, with similar high levels of CO_2, showed no differences in growth, although the plants with low nutrient sediments showed more prostrate growth forms with more stolon formation whereas the higher nutrient substrates showed more vertical growth form with less stolon formation. *Vallisernia* grown on hydrosoil from an acid lake had 81%, and *Vallisenria* grown in oligotrophic lake sediment had 47% as much biomass as plants grown on alkaline lake sediment (Titus, 1992). While this is one such study, a larger number of comparative studies would be a better indicator of trends and generalizations, although we now know a fair amount about *Vallisernia americana*. As hobbyists and scientist, we must be careful, not to suggest we know everything about all macrophytes by one such study on one species.

Water column nutrient effects:

Cedergreen and Madsen suggested with adequate nutrients in the water column, many submersed species will satisfy the nutrients needs through foliar uptake alone with no impact on growth rate (2001). How does a plant "decide" to produce more roots or less? Is root growth and architecture a response to low nutrients or competition? Are roots merely to anchor the plant to prevent floating away? Many suggest a plant "prefers" substrate nutrients merely based on the size of root mass. This is very misleading though.

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Many plants such as *Cryptocoryne*, and *Echinodorus* are from lotic (moving waters, such as streams, rivers) waters that vary greatly seasonally. Such plants would require strong roots systems to prevent being washed away by the current, many lotic fast flow water plants, produce long strap like leaves that reduce the pull such as Vallisernia and even C. crispatula var balansae. Such plants do poorly emergent whereas *Cryptocoryne*, and *Echinodorus* are well adapted to emergent growth and require roots for a source of nutrients. Water hyacinth (*Eichhornia crassipes*) possess large roots, being floating plants, obviously these are merely for water column uptake, thus implying all plants with large root systems prefer sediment uptake presents serious flaws. Further, both *Cryptocoryne*, and *Echinodorus* appear to be seasonal in their native habitat and also possess rhizomes that act as long term storage reserves. This suggests that such rhizomes are for harsh conditions, rather than any supposed preference. Further, studies can easily be preformed in inert sediments that maintain relatively free nutrients and nutrients can be added water column. Growth rates are rapid for both genera under such treatments suggesting that limitation of nutrients by aquarist in the water column, have led to this speculation. If the plant has no where else to obtain nutrients, and the nutrients are added to either location, the expectation is that the plant will grow with such treatments, regardless of where the nutrient is added. Some plant species specific test should be done in the future to compare such preferences as some may show preference, regardless of root architecture, biomass or root shoot ratio. Several researchers have shown that as water column nutrient levels decrease, root biomass increases (Cedergreen and Madsen, 2001). This makes sense as the plants have no where else to look for nutrient in the water column, so they try to find more in the sediment.

One of my client's tanks

Often an aquarist will have a plant that is not doing so well and they may add a fertilizer tablet under the plant and this appears to restore its health and growth. This leads the aquarist to believe that these plants prefer sediment fertilization. In terms of growth, the plant may have rapidly grown, then depleted the rate of nutrient input from fish, or their fertilization dosing, sword plants (*Echinodorus*) are rapid growing plants that become large. As they grow, they often dominate the aquarium. In terms of biomass, they can easily change from 1% of the tank to 80% of the tank's total biomass, as such, the rate of uptake from the water column is exceeded and adding nutrients to either the water column or the substrate can increase growth rates as the plant becomes large. Adding CO_2 to such plants also increases growth roughly by a factor ten time as well, but does the plant obtain the CO_2 from the sediments in this case or K^+? Generally not. A basic method is to simply try adding the nutrients to the water column and noting the changes in growth of such plants. The water column is much easier to test the levels for, where as the sediment is tougher for a hobbyist. Considerations should be made in terms of the plant's growth rate, the plants increase in size and location of the nutrients when looking at growth differences between such treatments. It should be noted that some plants may grow better with sediment based nutrients, and providing a combination of both water column and sediment sources will provide the best optimal growth for plants. Each species should be considered carefully when applying such correlative speculation and should not be assumed to be similar to every other plant.

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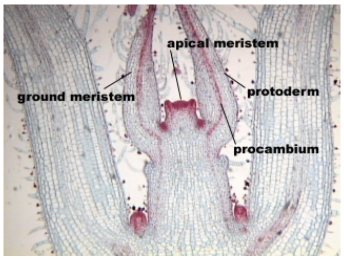
Growth in mature plants:

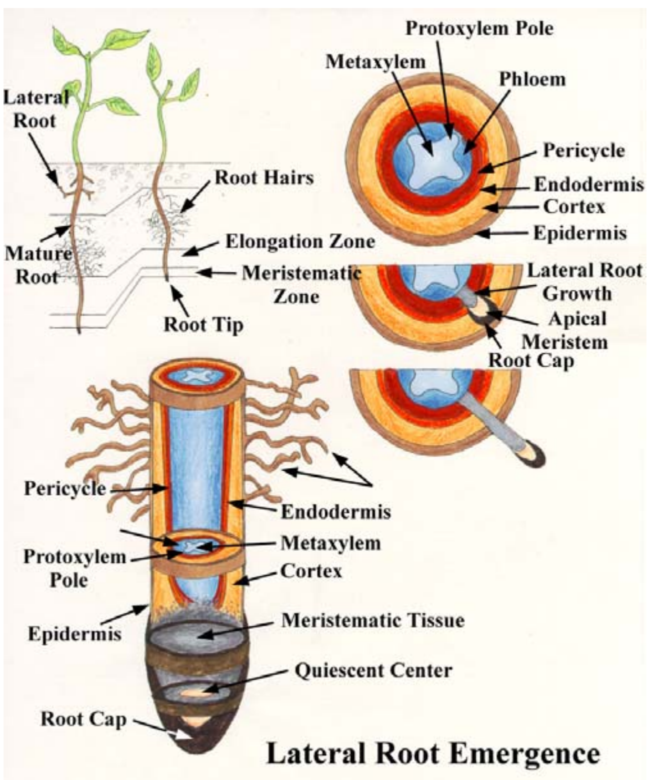
There are three main forms of growth in plants:

1. Apical meristems --> primary growth (shoot and root)

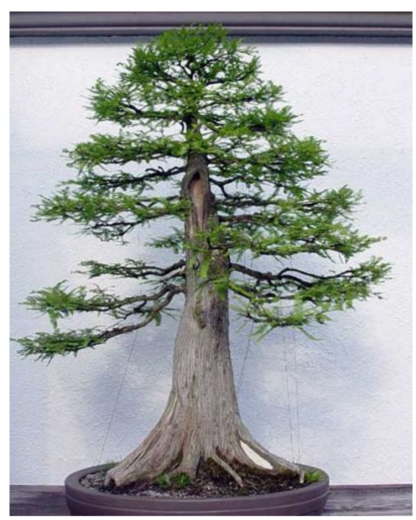


2. Lateral root formation

Lateral root develops from pericycle; cells divide, form a clump which elongates and pushes out through the root cortex. Vascular cylinder of lateral root retains connection with the "stele" (central vascular cylinder) of primary root
[This occurs in taproot system of dicots. Why is this not a good discription of what happens in monocots? (No taproot.)]



Observe this natural example of lateral root formation.



A bonsai Bald Cypress tree.

3. Secondary growth (woody plants)
   Occurs during second and successive growing seasons in all gymnosperms, most dicots; rare in monocots.

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Growth originates in vascular cambium, cork cambium (= lateral meristems) Bald Cypress and Mangroves are common wetland aquatic trees.

a. **vascular cambium --> secondary xylem, phloem**
   Vascular cambium = parenchyma cells that retain ability to divide; one, or a few cells thick; each growing season v.c. cells divide (mitosis) --> one daughter cell differentiates, the other remains meristematic [Fig. 29.21]
   Xylem forms on inner face of v.c.; phloem forms on outer face; early (spring) xylem cells have relatively large diameters and thin walls compared to xylem produced later in the summer (=late wood); this alternation of larger, thin-walled cells and narrower, thick-walled cells = annual growth layers (tree rings) [Fig. 29.24]
   Wood = tracheids, vessel elements and fibers
b. **cork cambium --> cork**
   - during secondary growth, epidermis from primary growth splits, dries and falls off stem
   - cells in outer cortex (outside secondary phloem) become meristematic and divide to form cork cells on outer perimeter; cork cells deposit waxy material (= suberin) in their cell walls, then die; cork = layers of dead cells
   - preiderm = cork cambium + cork; replaces epidermis, provides protection against pathogens, waxy walls retard water loss (bark includes periderm and phloem)

Conclusion:

Growth is meaningful when defined by the aquatic macrophyte hobbyist, researcher or layer person in a precise way. Many hobbyists tend to think of growth only in vegetative terms and often then only in terms of the shoot growth and length rather than biomass and root growth. Measurement of growth can be addressed by hobbyists in several ways that are relatively straight forward and practical. When comparisons between treatments are evaluated, care should be given to ensure that starting biomass is consistent and healthy, environmental conditions are non limiting and similar for both treatments. Plants also need to time to acclimate to new environments, generally about two to three weeks and taking the best two or three cuttings for each treatment test is typical. By pruning periodically, we export growth from the system. This maybe in the form of roots, shoots, or both. This periodic pruning will also affect growth rates, allowing the rates to be consistent over time. This in turn allows the uptake and stability of the system to be stable over time. If the aquarium is not pruned for long time periods, then the rates will slow down and stop. While they might stop their growth rate entirely, many systems will maintain a stable biomass. Limiting nutrients and CO_2 will also lower growth rates and reduce plant biomass maximum levels. In the past, some aquarist had suggested to limit PO_4 to slow growth in CO_2 enriched aquariums. Note, this is not absence of PO_4, it means to merely limit PO_4 to control plant growth rates. Perhaps a better method is to lower light intensity as it is the main driver and input of energy into the system, everything else is downstream of this.

What is optimal growth? Generally it may be defined by the maximum long term sustained growth rate that produced healthy vigorous macrophytes. For comparisons made against such a standard, the aquarist must first witness such growth optima. For the aquarist and research has no experience in what they are measuring without first having seen and experienced the growth in person. This presents a problem for many aquarists. While they may assume they are doing fine, they have not yet seen the intense growth that good CO_2 and PO_4 dosing may show, thus they accept that they are doing well and find little need to grow their plants at a higher rate. This maybe fine in terms of the hobby, but it is not when comparing methods, routines and uncovering new understandings beyond what is already known. Seeking such optima allows the hobbyist to see what such optimal rates of growth look like and allow them to compare other methods and changes to their own routines very effectively in terms of plant growth. This knowledge can then be used to apply to non CO_2 slower growth methods, marine methods or alterations of various methods to suit the hobbyist individual needs.

While optima and maximum growth are somewhat different, in many cases they are the same for hobbyists for a given light level. Few hobbyists go beyond 600 $umol/m^2/sec$ of light and driving CO_2 and nutrients to optimal levels is manageable for most aquarist. Usage of O_2 meters would be very effective to compare methods rather than testing of NO_3 and PO_4 to a large degree. There is enough causal effect established between $NO_3/PO_4/K$ and plant growth for some time now. What is more interesting perhaps too many and is perhaps the future horticultural issues are whole plant responses and measuring the pearling one sees and quantify that

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observation. O2 meters are an excellent way to achieve that. “Fat” and “starved” plant concept may help better to test and judge plants more effectively. “Fat” plants have a lot of reserves and it takes some time before these storage reserves are depleted. The same is not true for starved plants, they will respond quick and drastically to a limitation, whereas the same treatments done to a “Fat” plant might not show any effect for 2 weeks or more. So condition of the plants beforehand can make huge differences in the results.

Sediment and water column nutrient concentrations may change the morphology and health of the macrophytes. While some hobbyists have made assumptions about the nature of this growth, few if any have done so with base lines that isolated the water column and isolated the sediment sources effectively and under non limiting conditions. Thus the confounding factors influencing the results are impossible to tease apart under such conditions. This highlights the need and importance for base line comparisons under such treatments to show their effects on macrophyte’s growth rates. Often times there are many more possible and quite reasonable causes for large root systems that vary species to species for a variety of reasons unrelated to uptake, root systems maybe mere large storage organs as in sweet potato or *Nymphaea*. If non limiting water column conditions are not investigated when comparing growth rates, then little can be said about adding fertilizer to sediments, one would obviously expect higher growth rates if the fertilizer was added anywhere to an otherwise nutrient limited system. The cumulative effect of both locations for enhanced growth is of more interest and perhaps shows “preference” to some degree. Regulating the allocation or partioning between the root and shoot is an interesting subject (next month’s Article). How does the plant decide at the whole plant level? What role do hormones play?

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