GALLAUDET UNIVERSITY

THE HONORS PROGRAM

Turtle Town
Creating a Self-Sustainable Ecosystem Using an Ecological Approach to Turtle Aquarium Design

An Honors Capstone Submitted in Partial Fulfillment of the Requirements for Graduation with University Honors

By: Sheena K. O'Donnell

Committee Chair: Caroline Solomon, PhD
Second Reader: Daniel Lundberg, PhD

Honors Director: Shirley Shultz Myers, PhD
Honors Coordinator: Geoffrey Whitebread, MA

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ABSTRACT: Typical pet turtle tank setups do not utilize the complete nutrient cycle seen in a functional natural ecosystem. This dysfunction results in waste and nutrient buildup, which is currently managed by water changes and regular tank cleaning. This type of maintenance can be costly and time-consuming—not to mention, unpleasant and hazardous to the aquarium owner's health. This study tested the effectiveness of using plants as part of a proposed ecological tank design to minimize waste buildup by utilizing nutrients. Wastewater from a dirty turtle tank was transferred to a tank setup containing three plants (Experimental Batch 1), while the dirty turtle tank received clean water (Experimental Batch 2). Water samples were collected from each tank over a period of approximately two weeks and each tank's concentrations of phosphorus and nitrogen were measured. NH_4^+ analysis results showed that the rate of turtle N buildup equals about 4.5 times as much as plant N use. PO_4^{3-} analysis results showed that the rate of turtle P buildup is about 0.2642 μM per day, however plant P use did not show a significant trend. Further studies on plant P use and forms of N should be carried out to explore this anomaly. Results from this study and further studies of its kind can be used to estimate and standardize the amount of plant mass needed to create a self-sustainable cycle in a 40-gallon tank. Turtle owners can use this information to improve the water quality, using an ecologically friendly design. In future studies, researchers can test further other additions to create a complete ecological tank design - including organic filter sponges, a worm compost farm, and a complete garden situated above the tank - against typical mechanical filtration systems to compare quality of life for the turtles.

Contents

INTRODUCTION

Aquaricycle. Aquariums provide a fun, decorative, and scientific approach to a hobby, a project, or a children's lesson in responsibility. Although most people might think primarily of fish, aquariums or the tanks used for them can house other creatures that live partially or wholly in water, including crustaceans such as crabs and lobsters, snails, amphibians like newt and frogs, and reptiles such as snakes and turtles.[1] While these animals within aquariums can bring their owners the joys of pets, they also require hours of maintenance to keep the animals in the tank alive.[2] Because of the time and also the cost involved, maintenance is a challenge. Hence, it is not surprising that 50-90% of reptiles, for example, end up dying within a year in captivity.[3] One popular group of reptiles is aquatic turtles (red-eared sliders, box turtles, painted turtles) that often do not survive in captivity because owners do not provide large enough tanks for them to grow. Again, however, a large tank means more maintenance in time and money. The high mortality rate does not deter future pet owners from buying these turtles; they are a popular species, often described as friendlier than other captive turtle species.[4] These turtles and their owners would benefit from more efficient and less expensive maintenance. This project involves two parts. One is the application of principles of ecology to design a turtle tank set up that could reduce the overall aquarium maintenance costs for turtle owners. The other, the aim of this thesis, is an experiment that tests one part of this design concerned with the use of plants for filtration.

A typical aquarium setup today for aquatic turtles require frequent and extensive manual cleaning. Without cleaning and regular changes the water quality quickly degrades and eventually becomes inhabitable for turtles, putting both the pets and the owner(s) at risk of infection and illness.[5,6]

One way to reduce work involved with aquarium maintenance is to design an efficient tank setup with particular focus on waste clean-up method(s) used. The most economical and effective solution is to take an ecological approach aiming to create a self-sustaining freshwater aquarium setup. The desired outcome for this project is an aquarium setup that requires minimal input and maximizes the cycling of nutrients such that the input and output of nutrients is balanced, leading to less waste production and maintenance requirements.

This design serves as an alternative to commercial tanks that are not eco-friendly, economical tanks for pet turtles. Although not the focus of research, better tank design involves aspects similar to work in other areas, such as "aquaponics," the integration of hydroponics with aquaculture, as reported by the National Center for Appropriate Technology.[7] A great deal of work has been done on aquaculture in large-scale fisheries, ranging from master's theses to business plans.[8,9]

Problems with Tank Designs. Understanding how to minimize waste buildup in aquariums requires applying principles of nutrient cycling. Nitrogen (N) and phosphorus (P) are found in turtle food and waste, and at high levels can potentially cause complicated problems in an ecosystem. Managing levels of N and P is a challenge on the global scale in coastal ecosystems[10], but applies equally in a on a smaller scale such as a turtle tank.

A large body of literature has focused on the removal of nitrogenous wastes from water because they can be toxic at high levels and build up as sludge. The most toxic molecules in groundwater are nitrogenous, particularly ammonium (NH_4^+), nitrite (NO_2^-), and nitrate

(NO_3^-). In wastewater, nitrates are the central focus in various types of sewage and drinking water treatment because they are the largest percentage of plant-available nitrogen in wastewater, and will cause algal blooms, some of which may be toxic.[10,11,12,13] These nutrients cause eutrophication in both marine and freshwater aquarium setups, leading commercial aquarium care products to focus on the removal of one or more of these nutrients from the water.[14]

Another essential nutrient in an ecosystem is phosphate (PO_4^{3-}). This compound contains phosphorus, which along with nitrogen, oxygen, and carbon, is a critical element for the growth and survival of all organisms. While carbon and oxygen are typically abundant, nitrogen and phosphorus are usually bioavailable in smaller amounts. For this reason, ammonium (NH_4^+) and phosphate (PO_4^{3-}) are the central focus since they are the limiting nutrients of most ecosystems and the forms of nitrogen and phosphorus that plants favor most.

In a functioning ecosystem, the waste from one organism waste is a source of nutrients for other organisms. For instance, bacteria in the tank will decompose feces into NH_4^+ and PO_4^{3-} available for plant use. Plants utilize these nutrients for growth and metabolism, and are themselves a food source for the turtles. Animals use PO_4^{3-} from food for DNA, cellular membranes, hair, skin, shells, energy transfer, and more. A tank without plants, therefore, results in an incomplete or unbalanced ecosystem (Figure 1).

A nitrogen cycle occurring in a regular aquarium setup involves adding nitrogen via food or other types of plant and/or animal matter. This nitrogen is digested by the turtle(s) who release NH_4^+ and feces as waste products. Various strains of bacteria convert the NH_4^+ to less toxic forms of nitrogen—*Nitrosomonas,* for example, convert ammonia into nitrites, while *Nitrospira* further convert nitrites into nitrates.[15] While these two oxidized forms are in effect less toxic than NH_4^+, the only ways to fully remove N are water changes, or, when N is in solid form, by various mechanical filtration mechanisms.[15]

Similar to nitrogen, the phosphorus cycle in an aquarium begins with the addition of food. Skin and shell pieces shed by the turtles, as well as feces and other waste build up as sediments also release PO_4^{3-} by decomposition. PO_4^{3-} is not highly soluble in water, however, and tends to form precipitates. In high concentrations, N and P can cause favorable conditions for algal blooms and excessive plant growth. Algal blooms can be harmful in themselves and, like excessive plant growth, use dissolved oxygen in the water and decreases the health of the tank overall – a process known as eutrophication when left unchecked.[16]

The buildup of waste nutrients that cause these problems can be prevented or the effects of it can be mitigated by several methods; scrubbing the surfaces on which algae grows, changing filter media often, adding chemical water treatments such as API Turtle Sludge Destroyer which contains decomposing bacteria[17], or changing the water. Aquarium owners worldwide agree that these tasks can be costly, time-consuming, and unpleasant.[18] If there were a way to add a component capable of removal of nutrients to offset what has been added by food, we could strive to have minimal water changes.

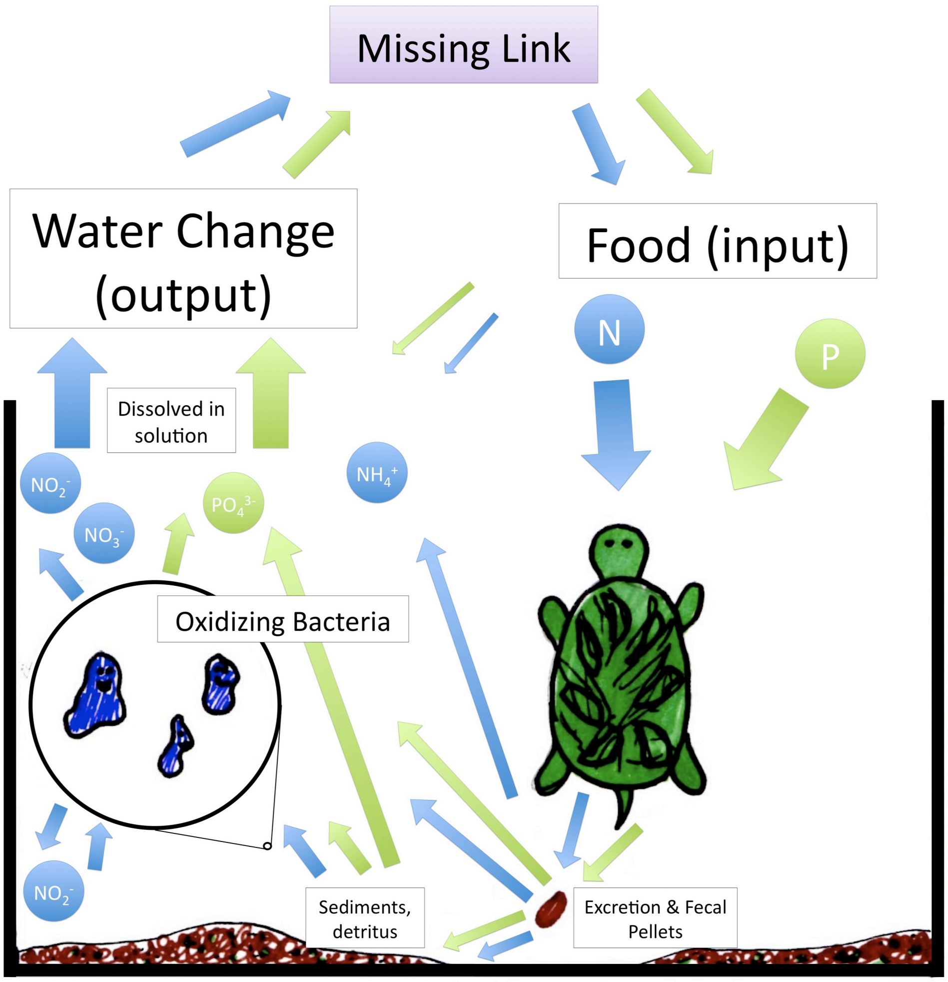


Figure 1: Aquarium Nutrient Cycle

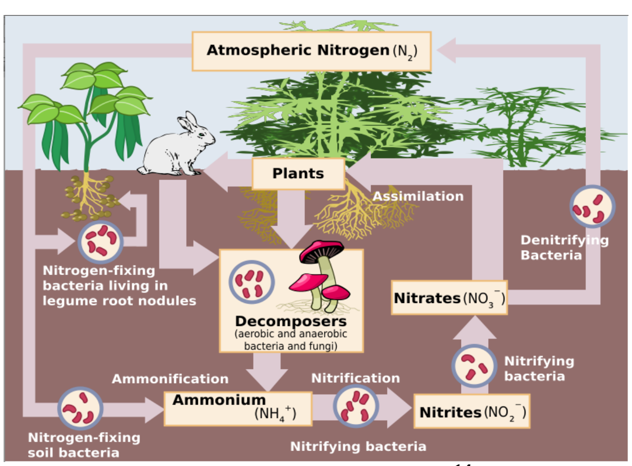


Figure 2: Nitrogen Cycle[14]

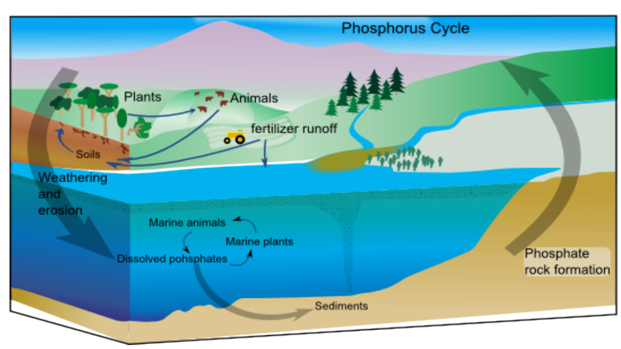


Figure 3: Phosphorus Cycle[15]

SOLUTIONS TO TANK DESIGNS

This section discusses the missing steps that can be added to complete the N and P cycles, the physical solutions that can represent the missing steps, and the ways these solutions could logically work together. To reduce build up of nutrients such as N and P in an aquarium, consideration of the complete N and P cycles as they would occur in the natural ecosystem allows identification of the components needed in a revised aquarium that are not present in a typical aquarium design.

The nitrogen and phosphorus cycles in natural ecosystems allow nitrogen and phosphorus to be used efficiently at each step (Figures 2 & 3).[19,20] In the first step, plants use NH_4^+ and PO_4^{3-}, found in organisms, their excretions, and fecal pellets, as a source of nutrients for growth. Nitrogen can be removed by denitrifying bacteria, which convert NH_4^+ to molecular nitrogen (N_2). This molecular nitrogen is released to the atmosphere in gaseous form, and is biologically unavailable.[10] Phosphorus can become biologically unavailable or removed from the system when precipitated and settle at the bottom as sediments. In an aquarium, however, the build-up of waste results from the lack of an "escape route" for nitrogen and phosphorus after they are excreted as waste. Theoretically, mimicking a natural ecosystem by providing missing links in the nutrient cycles of nitrogen and phosphorus should help minimize the need for the filtration and water changing process (Figure 4). To provide the missing link, I offer two possible changes or additions to the traditional tank design.

Solution 1: Garden. An external garden, situated above the tank, provides a basking area for the turtles and a source of food if compatible plants are chosen. Turtles use a ramp to travel freely between water and land. The garden serves two purposes. First, it provides a natural, space-saving alternative to an artificial floating device that would otherwise be needed for a basking area. Second, the garden plants improve water quality by removing nutrients. Aquatic plants have been known to help keep an aquarium clean by using nutrients dissolved in the water so that many aquarium enthusiasts swear by the incorporation of aquatic plants in their tank setup.[21] In contrast to fully aquatic plants, which grow submerged in water, the plants used in the garden grow on rocks, which have the added advantage of serving as a surface for some of the nutrient-containing solids, having escaped solids filtration, to adhere to. Otherwise the solid waste that was able to pass through the first trap (organic sponge-like filter) would be dumped back into the tank and degrade the water quality quickly.

Solution 2: Water & Nutrient Flow. Because NH_4^+ and PO_4^{3-} dissolve in water, the flow of the nutrients follows the pathway of water as it moves through the tank. The water from the tank leaves through a hole drilled in the tank, which is lined with a watertight medium to prevent leakage. This hole also has a shut-off valve, left open for the majority of the time but present for filter changing purposes. The water feeds through a hose into a mechanical filter casing, where any type of organic and flexible sponge-like material can be housed, for example, a loofah sponge. This material catches solid waste, such as feces and shed turtle shell pieces suspended in the water. The fibrous property is a key feature, as it provides sufficient surface area for microbes and bacteria that break down solid waste to grow, and it also provides a trapping mechanism for particulate matter to be broken down rather than be accumulated in the garden.[22] The relatively clean water then leaves the sponge-like filter and passes through the pump that pulls the water through the system. After passing through the pump, the water can then be directed to leave through the effluent hose back into the tank, or into a small garden situated above the tank. This garden has various small plants that are non-toxic, fairly resilient, and edible--there are many--for red eared sliders. The plants will grow on rocks as opposed to soil, because rocks will not cling to the turtles as they explore the garden. The effluent water will ideally supply the plants with nutrients while passing through the plant housing, then will return to the tank.

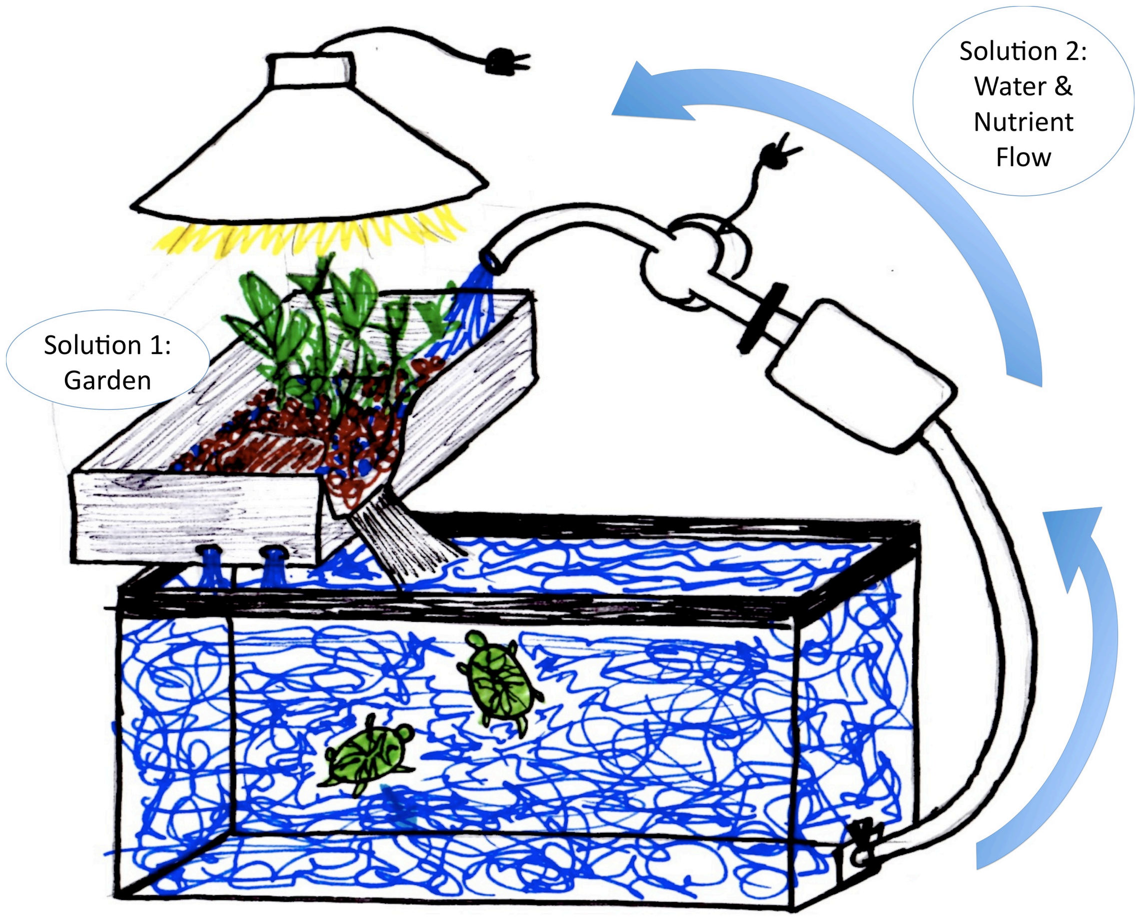


Figure 4: Revised Aquarium Design

MATERIALS & METHODS

Testing the sustainability of the revised aquarium design. Nutrient cycling involves several reservoirs, but the flow through the cycle from one compartment to another is not at the same rates or as one form.

The tank is designed based on the assumption that the nutrient supply from excretion and defecation of turtles is equal to the demand to support a plant garden. It is possible that the amount of plants required to utilize the amount of nutrients produced by the turtles would render the garden impractical because the garden might have to be significantly larger than the tank itself in order to support a sufficient amount of plants.

In a pilot experiment, an aliquot of water from the preliminary tank that had turtles for the prior 8 months (visibly dirty with waste) was used in a hydroponic setup with aquatic plants (*Echinodorus bleheri, Dracaena braunii, Phalaris arundinacea*). The plants thrived and continued to grow and survive with water that previously had turtles, an oxygen bubbler (air stone), and indirect natural light from a nearby window. This result signified that the water itself had the necessary nutrients present to support the plants, but more data on nutrient levels and the changes in those levels is needed to verify the sustainability of such a setup over a long period of time.

To investigate this possibility of sustainability, nutrient levels in two experimental tanks were measured to help determine if building the more complex tank design would be warranted. If the nutrient buildup from turtle excretion and defecation could be closely matched by the utilization by plants, building additional features to the aquarium design could proceed.

This experiment focused on whether the supply of nutrients provided by excretion and defecation by the turtles equaled the amount of nutrients utilized up by the plants, and the difference in production and utilization rates. The amount of nutrients utilized by the plants may be extrapolated to match the amount excreted by the turtles to estimate how many plants would be needed for this purpose. These results will help determine the plausibility of building a sustainable functioning tank design in a practical amount of space in a home setting.

Experimental Batch 1: Plants. The preliminary turtle tank (40 gallon tank size) setup was about halfway full with visibly dirty water, which had greenish-brown particles that had settled on the bottom and in corners. This water, about 10 gallons in volume, had been in the tank for the 8 months prior to the experiment and was diluted to about 30 gallons by adding tap water. The diluted solution is referred to as "Experimental Batch 1: Plants" and was used to fill the 10-gallon tank used to house the plants. This 10-gallon tank setup is used to determine the rate of nutrient utilization by plants. The water from this dilution is labeled "Experimental Batch 1: Plants" and started out in the 40-gallon turtle tank, but after the first sample collection it was transferred to a 10-gallon plant tank for the rest of the experiment (discussed in the next paragraph). For this reason, the bodies of water in each tank are named as "Batches", not as "Tanks". The turtle tank volume was estimated by measuring the width, height, and length of the tank, to help determine ¼ of the volume for dilution.

After dilution, Experimental Batch 1 was left in the 40-gallon turtle tank to run for 2 days, to allow the water to thoroughly mix. After the two days, the first sample of Experimental Batch 1 (Sample #B1S1) was collected out of the 40-gallon turtle tank, launching the start of the experiment on Day #1 (See Figures 7-10).

On Day #1, after Sample #B1S1 was taken, 10 gallons of Experimental Batch 1's water was moved to the 10-gallon plant tank (Figure 7). Four plants (*Echinodorus bleheri, Dracaena braunii, Phalaris arundinacea*) were planted in this tank, which was at this time filled with Experimental Batch 1. An oxygen bubbler was placed in the tank to allow for water mixing. The plants were planted in netted pots filled with rocks, and these were held at the top of the water by a plastic storage box top. This box top had holes in it for the pots to feed through into the water. The plant tank setup, now holding water from Experimental Batch 1, also had a light hooked up to a timer set to turn on from 9am to 3pm every day. The samples for "Experimental Batch 1: Plants" are labeled "B1S2, B1S3, …" and taken from this 10-gallon plant tank (Figure 5).

Experimental Batch 2: Turtles. The remaining Experimental Batch 1 water from the dilution explained above was discarded, and the 40-gallon turtle tank emptied. The filter sponges in the turtle tank's filter (note that this is not the one discussed in "Solutions to Tank Designs" – it is a typical submerged sponge filter) were changed, and the tank was filled to the 30-gallon mark with clean, new tap water. This solution is referred to as "Experimental Batch 2: Turtles" and will be used to determine the rate of nutrient accumulation from the turtle waste. The samples for "Experimental Batch 2: Turtles" are labeled "B2S1, B2S2, …" and taken from this 40-gallon turtle tank (Figure 6).

Sampling & Analysis. Water samples were taken every 2-4 days from each tank (40-gallon turtle tank holding Experimental Batch 2: Turtles; 10-gallon plant tank holding Experimental Batch 1: Plants). The samples were filtered through a 0.45-µm GF/F filter, and frozen until ready for analysis in the lab. The samples' NH_4^+ concentrations were analyzed using procedures from *A Manual of Chemical and Biological Methods for Seawater Analysis.*[23] This procedure determines NH_4^+ concentration by forming a colored compound in alkaline solution that absorbs light at 640nm; the amount of light absorbed at this wavelength is directly proportional to the NH_4^+ concentration in the sample. PO_4^{3-} determination also used a colorimetric method, found in *Standard Methods for the Examination of Wastewater*.[24] In this procedure the samples were digested in acid with potassium persulfate, then mixed with a combined reagent which causes P to form a colored compound that absorbs light at 880nm, and the amount of light absorbed is proportional to the concentration of P in the sample. There were a total of 16 samples: 14 from the two tanks, one tap water sample (#B2S0), and one sample of food dissolved in distilled water. Concentrations of PO_4^{3-} in almost all samples were outside the acceptable range of standards prepared on the first run, so the samples had to be diluted and re-tested twice to get acceptable PO_4^{3-} concentrations. Results reported are from the second two runs. NH_4^+ concentrations for samples were within the acceptable range and only had to be tested once, except for the food sample. The food sample NH_4^+ concentration was not within the acceptable range, and a diluted sample was not tested because of time constraints.

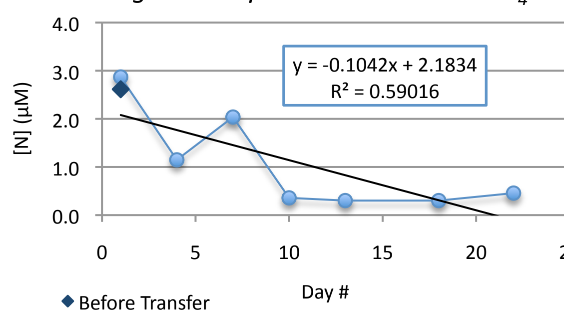
Figure 5: Plant Tank (Experimental Batch 1)

Figure 6: Turtle Tank (Experimental Batch 2)

RESULTS & DISCUSSION

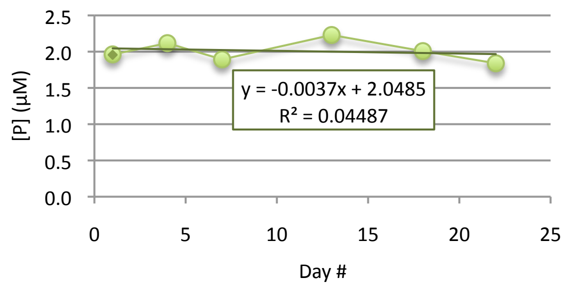
Experimental Batch 1: Plants. *NH_4^+ Analysis.* NH_4^+ concentrations decreased over time in Experimental Batch 1 (Figure 7). The relationship between time and Experimental Batch 1 NH_4^+ level shows a moderately high negative linear relationship, with $r = -0.7682$.[25] It is important to consider, however, that biological systems have many variables capable of affecting these results, and the *r* value only reflects how closely the data follows a linear trend. Nutrient levels and other parameters in a biological system will fluctuate often but the system as a whole tends to ease toward a dynamic equilibrium, which may or may not follow a linear trend. The negative linear trend observed here is therefore not precise, though it can be used to estimate how much plant mass is necessary to add during the initial setup of the complete tank design.

Figure 7: Experimental Batch 1 NH_4^+



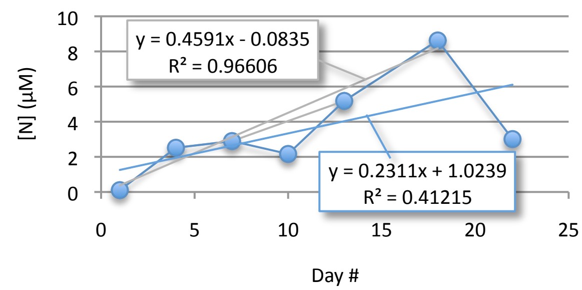
Total Dissolved PO_4^{3-} Analysis. Phosphorus concentrations in Experimental Batch 1 do not show an overall decrease (Figure 8). A trendline for this data shows both a low r^2 and a low slope value, so phosphorus levels seem to have stayed relatively constant, ranging between 1.8-2.3 µM PO_4^{3-}. Dilutions had to be prepared for all of these samples, so error in the methodology could account for the variability in the concentration. Due to the high likelihood of dilution imprecision and the absence of a significant statistical correlation, it is probable that the phosphorus levels in the tank stayed the same throughout the sampling period. This type of experiment could benefit from more days of observation, or from measuring total phosphorus, not just dissolved phosphorus.

Figure 8: Experimental Batch 1 PO_4^{3-}



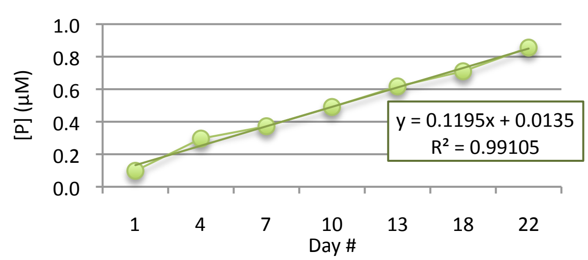
Experimental Batch 2: Turtles. *NH_4^+ Analysis.* Experimental Batch 2 showed a steady increase in NH_4^+ concentrations (Figure 9). The linear correlation is strong for this, with an r^2=0.96606, with the removal of the samples taken on Days #10 and #22. Including these two samples gives an r^2=0.41215. NH_4^+ levels were expected to steadily increase in Experimental Batch 2 because food is being added and nothing is being removed, leaving the NH_4^+ from excretion, defecation, and food remnants nowhere to go but in the water. However, the samples taken on Days #10 and #22 do not fit the expected pattern, while all the other samples do. To explore this anomaly, the two points were removed and a second linear trendline was applied, the correlation of which had a much higher value at r^2=0.96606 (Figure 9). If the two points are outliers and are not accurate representations of the NH_4^+ concentration on that day, then the data shows a strong positive relationship between time passed and NH_4^+ concentrations in this tank. Even if the two points are not an error and are indeed accurate measures of the NH_4^+ concentration at that time, the change in NH_4^+ concentration in this batch of water shows the most rapid change in nutrient levels in either experimental batch. The NH_4^+ concentration rose from 0.104 µM NH_4^+ in clean tap water to 8.623 µM NH_4^+ in just 18 days.

Figure 9: Experimental Batch 2 NH_4^+



Total Dissolved PO_4^{3-} Analysis. The turtle tank's PO_4^{3-} concentrations did not increase as quickly as the NH_4^+ concentrations did (Figure 10). The maximum concentration of PO_4^{3-} recorded was 0.86 µM. However, the positive relationship between PO_4^{3-} concentration and time was r^2= 0.99105, which suggests that PO_4^{3-} was continually excreted by the turtles.

Figure 10: Experimental Batch 2 PO_4^{3-}



CONCLUSIONS

Nutrient Usage & Buildup Rates. *NH_4^+ concentrations.* Turtle excretion and defecation produced ample concentrations of nutrients as the NH_4^+ concentrations in

Experimental Batch 2 increased at a rate of 0.4591 µM per day, while the NH_4^+ levels in Experimental Batch 1 only declined by 0.1042 µM per day. In terms of NH_4^+, this result can be used to estimate that the proposed tank design in Figure 4 would require at least (0.4591 µM NH_4^+)/(0.1042 µM NH_4^+) = 4.406 times as much plant mass as was present in the tank that held Experimental Batch 1. The tank holding Experimental Batch 1 had only four (small) plants, meaning about 16-20 of the same size plants would be needed to use up the NH_4^+ at a rate shown in Figure 9.

Total Dissolved PO_4^{3-} concentrations. The phosphorus concentrations of the two tanks do not have patterns that are useful in determining how many plants would be needed to balance the demand for phosphorus. Because the plant biomass and the PO_4^{3-} concentrations in Experimental Batch 1 did not change much over time, it is not possible to extrapolate this rate to estimate how many plants would be needed for the use of PO_4^{3-}.

Methodological Fine-Tuning. *Tank setups.* In further experiments, plants should be exposed to water that is not as saturated with excretion and defecation waste as Experimental Batch 1 was. The characteristics of the water from the preliminary tank and the constituents can change and react, so it is possible that the forms of P observed in the Experimental Batch 1 were not those that are biologically available. Moreover, the fact that the turtles and the plants were not in contact in the same tank may have affected the nutrient concentrations. For example, PO_4^{3-} is not highly soluble in solutions with high dissolved oxygen[10]. However, the tank holding Experimental Batch 1 had an oxygen bubbler, as most hydroponic plant setups do, to avoid the water getting stagnant. This may have played a part in the high levels of P being detected but no change occurring because it is possible that the PO_4^{3-} ions were tightly bound to some substrate in solution that it normally would not bind to in solutions with lower oxygen levels. This same reasoning could also lead to the conclusion that much more PO_4^{3-} was present than was accounted for, since only dissolved P was measured as solids were filtered out. Another tank setup feature used in this experiment that should not be used in the next is the presence of rocks in the tank holding Experimental Batch 1. Rocks were used for support for the plant so the roots could have something to anchor to, but rocks are themselves a source of phosphorus, a fact that was overlooked during setup planning.

Phosphorus Analysis Procedures. The procedures used to analyze the levels of PO_4^{3-} were written for the analysis of total PO_4^{3-} (including organic and biologically unavailable PO_4^{3-}). This method accounts for dissolved PO_4^{3-} as well as P present in the sediments and precipitates in the water. In the procedure, the samples are digested with acid and potassium persulfate in order to release the PO_4^{3-} ion before the colorimetric analysis. Plants do not use organic forms of PO_4^{3-} - only the ion when it is dissolved in solution. The method used may have accounted for PO_4^{3-} present but biologically unavailable, and may have led to the very high concentrations and no change.

Next Steps. *Oxidation of N.* It is important to explore the fact that the rate of buildup in Experimental Batch 2 quickly brought NH_4^+ levels higher than the amount that Experimental Batch 1 started with. The plants started with water that had been in the turtle tank for several months without water changes prior to their exposure, so it would be expected that nutrient levels would be much higher in Experimental Batch 1 (with plants) than in Experimental Batch 2 (with turtles). It is possible that other forms of N waste were present in Experimental Batch 1. Analyses should be carried out to determine levels of NO_2^- and NO_3^- in each of the two tanks. Results from such analyses could help find whether all N gets used up as NH_4^+ or if there are other forms present that can or will be utilized by the plants. This information will be useful because if more N is present in other forms then plants can use this N for further growth and metabolism. If there are no other forms of N utilized by plants then the information found in this experiment shows that there is not enough N for the necessary chemical reactions to occur to use up the P that is present.

Different Compounds containing N and P. If there are indeed other forms of N then the nutrient concentrations and changes in each situation could be further tested to determine which compounds containing N and P are present, and if the necessary conversions between them are occurring via various bacteria to make N and P biologically available. This involves analyses of all forms of N and P and their concentrations present in the tanks.

ADDITIONAL SOLUTIONS

Different perspectives and approaches are necessary to create a lasting solution to problems in turtle aquarium design. With that being said, many different sources of energy and ways to use nutrients could be used in place of, or in addition to, adding plants to the proposed tank design that has been discussed. The purpose of this section is to provide additional methods of ecologically sound aquarium maintenance, as well as additional methods of filtration to increase efficiency. Unfortunately, it takes a lot of patience and time to establish a sort of equilibrium such that the water does not have to be changed at all, so some modifications or additions to make the tank design's full ecosystematic function a reality are discussed here.

Solar Power. A power source is necessary for some components: light for plants and for basking, and the water pump. If the tank is placed in an area that gets reasonable sunlight, the heat lamp fixture used in a traditional aquarium setup is not needed. These lamps can use light bulbs that put out an average amount of power found in a regular light bulb used to light a room. These light fixtures use up to 160-watt light bulbs.[26] An adjustable water filter made by Fluval that can pump 1000L of water per hour uses about 10 watts, and is reported to be compatible with a 215L tank.[27] Therefore a water pump needs to be chosen to create a home-made mechanical filter that matches the power usage and water flow rates of the pump used for the commercial filter, or perhaps a higher value of 20 watts. Adding the two energy demands together gives a total of about 180 watts needed to maintain the tank. Choosing a solar panel with the capacity to produce more than 180 watts (e.g. 200-250 watts) should give sufficient room for error.

Worm Compost Farm. An alternative method of dealing with excretion and defecation waste and supplying the garden with appropriate and substantial nutrients is to use the waste to feed worms housed in a compost farm, which will then be harvested to use as fertilizer and soil for plants in the garden. This potentially serves as part of the missing step discussed in the nutrient cycle

(Figure 1); the wastes from the turtles and the organic filter media can be digested by the worms, as well as the dead plant matter and the scales shed from the turtles, to create new plant food for the plants. The compost can be soaked in water to make "worm tea", but the liquid drainage directly from leaching of the compost in the bin is still toxic and may need to be treated further before use.[28,29,30] While this still is missing a step in the nutrient cycle it makes much less of an imbalance, and provides a quicker, easier, and less wasteful way to clean a tank. Moreover, the worms can be fed to the turtles as a source of protein instead of commercial store-bought food.

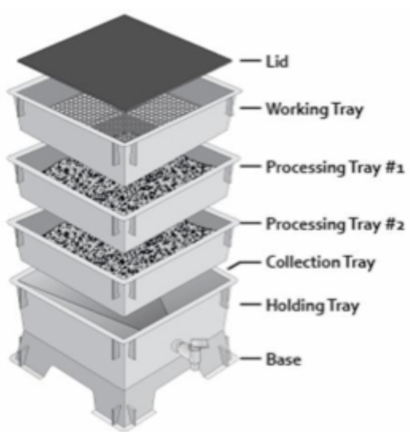


Figure 11: Worm Compost Farm Design[31]

The Worm Factory® 360 boasts a patented design requiring minimal maintenance (Figure 11).[28] The worms are housed in the different processing and working trays, and mimic the different levels and layers of soil microenvironments found in a natural ecosystem. Adding garbage, or in this case, solid waste from the turtles, to the top shelf at a balanced rate gives more food at the top for the worms to eat, so they crawl upwards as they run out of food to eat in the lower bins, making the harvest of the actual compost easy.

Other Waste Processing Options. In place of or as a supplement to worm composting, the system may benefit from the incorporation of another form of waste treatment to avoid toxic runoff back into the aquarium. Since run-off may occur because nutrient balances could take a long time to stabilize, it may be necessary to detoxify or stabilize the waste accumulated so it are not as volatile and dangerous to caretakers as well as the aquarium inhabitants. The Blue Plains Advanced Wastewater Treatment Plant, operated by DC Water, implements a program that concentrates the waste found in sludge, neutralizes and disinfects it, and uses the product for various energy-efficient purposes like burning as fuel or use as fertilizer in landfills.[32] A similar approach could be used for solids collected from turtle aquariums. However, it is not as simple as just concentrating the waste and directly applying manure to the land. This would cause various environmental problems to develop like odors, toxic compounds present in soil, and sometimes trace elements that can be taken up by the plant(s) which can subsequently cause them harm or are inevitably ingested by other organisms; hence the necessity for classifications of the wastes (termed "biosolids") that determine the level of control that is exercised on the commercial use of them.[33] The biosolids' planned method of application, and the level of processing it has been subjected to, determine the restrictions placed on the use of the biosolid as fertilizer or soil enrichment. Restrictions, for the purpose of limiting exposure of potentially toxic compounds, include: placing minimum time frames between time of application and time of harvest for use; limiting allowable application areas of certain classes of biosolids (for example, forbidding the direct application of class B liquid-form biosolids to a school baseball field); requiring detailed plans and specifications including nutrient flux rates of the area, plants to be fertilized, and biosolids that will be used, to prove the maximum efficiency of the biosolids' use.[33] More information on biosolids classification and restrictions to public and commercial land application use can be found at the DC Water website, EPA website, and the National Biosolids Partnership Website.[32,33,34,35,36] Particularly of interest to this system – for the purposes of cost efficiency – is the process of alkalization of the solids. The EPA reports that Class B biosolids can be produced if the material reaches a pH of 12 after 2 hours of contact with the alkalizing material, which is typically a type of product that is commercially available such as hydrated lime.[35,36] To use this mechanism, a filter media that is either also organic or capable of desorbing the sludge that has adsorbed to it can be used in the filter canister before the pump in Figure 4, the sludge could be collected and treated with the hydrated lime, and the biosolid form of the sludge could then be applied to the garden as fertilizer.

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