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Energy, carbon dioxide and economic comparisons of tilapia sp. nnd cyprinus carpio in aquaponics system.

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Abstract: Aquaponics is a food production system that combines conventional aquaculture (raising fish) with hydroponics (cultivation of plants in water) in order to utilize the fish waste as a substrate for plants. In this study both Tilapia sp. and Cyprinus carpio (Koi) were compared to see the differences between food fish (Tilapia) and ornamental fish (Koi) in terms of energy and economics. Measurements of the electricity and CO_2 emissions pulled during fish growth were calculated. The amount of CO_2 produced from Koi was 3.6269 x 10-10 tonne CO2/tonne fish and Tilapia was 2.2029 x 10-10 CO2 tonne /tonne fish. It was found that Tilapia had a feed conversion ratio of 1.73 and Koi had 1.52, showing an increased ability to convert food to weight. It was also found that Koi have a higher retail value than Tilapia.

Keywords: Aquaponics, Tilapia s.,Cyprinus carpio, energy

Introduction

Aquaponics is the marriage of hydroponics and aquaculture, creating a unique system that can limit waste and produce more food per unit space. Hydroponics is the growth of plants in water run systems with substrates other than soil or sometimes using no substrates at all. Aquaculture is the growing of fish and living organisms for human consumption within aquatic environments. Aquaponics uses waste generated by fish as plant nutrients whithin a recirculating system that returns clean water back to the fish. In this way, fewer resources are used and a smaller areas for grow beds are required. (Endut et. al, 2011).

Fish excrete ammonia and the bacteria (Nitrosomonas and Nitrobacter) process it turning into nitrite and then nitrate which can be used by the plants for growth. The water is filtered by the plants and returns into the fish tanks (Metcalf and Eddy, 1991). In this system, the expanded shale present in the grow beds are important due to the great amount of pockets with large surface area for nitrifying bacteria to attach to and thus a better ability to digest ammonia into nitrite and then into nitrate. In addition, the bacteria have optimal living conditions at 77 to 86^{o}F and a pH between 7 and 9 (Rakocy et. al, 2006). Tilapia have optimal growing conditions at 81 to 84°F (DeLong et. al 2009) and an optimal pH of 6 to 9 (Popma and Masser, 1999), whereas Koi has optimal temperatures between 65 to 75^{o}F and a pH of 7 (Craig et. Al, 2004). Tilapia nitrite levels must be kept below 5 ppm (Rakocy, 1989) and ammonia levels should be kept below 0.20 ppm (Popma and Masser, 1999). Koi nitrite and ammonia levels should not go above 0.05 ppm (Craig et. al, 2004). Most plants grow best at a pH of 5.8 - 6.2 and a temperature of 75^{o}F. However, cold weather plants may enjoy a water temperature in the 60^{o}F range.

Nutrients availability is dependent on the pH of the system. A pH higher than 7 restricts the availability of iron, manganese, copper, zinc and boron to the plants while a pH lower than 6 restricts the solubility of phosphorus, calcium, magnesium and molybdenum into the system (Rakocy et. al, 2006). Plants would prefer a neutral to slightly acidic pH, while the fish and bacteria would prefer a neutral to alkaline pH. If the pH goes out of its optimal range for bacteria, the ability of the system to process ammonia will decrease and may cause the system to fail. Taking this into consideration, fish and plants should be picked that meet ranges complimentary to each other to prevent stress. When these systems are conducted in an optimum manner, the removal of total ammonia, nitrite-N, nitrate-N and orthophosphate can occur at efficiencies over 70% (Endut et. al, 2011).

Many of these systems produce edible fish for profit. Koi are a slower growing fish (Craig et. al, 2004) than Tilapia, which feed ferociously and increase in mass significantly over a short period of time (Rakocy, 1989). The focus of this study was primarily economic. Can the rapid growth and low economic value of Tilapia compete economically with the Koi's high economic value but slower growth rates? Additionally, the amount of food vs. the weight gained also gave the feed conversion ratios and the cost to grow the fish. Harvested lettuces caloric content was calculated, in order to estimate the amount of energy passing from the calories in the food to the fish and then to the plants. Finally, a calculation of the carbon footprint of running this system was determined by looking at all electricity used.

Experimental

Each system was comprised of a gravel bed hydroponic vegetable system and a fish tank, both fabricated from food grade plastic barrels laid horizontally in a cradle. The fish tank held 180 liters and the gravel biofilter held 90 liters. The function of the biofilter was to convert ammonia to nitrate and to remove particulate solids from the waste. The biofilters operated on a flood and drain interval of approximately 10 minutes, cycling the entire tank water in approximately one hour.

Filtering and oxygenation of the water occurred constantly; filtration occurred through bio-filtration (via the growth of bacteria and uptake of nutrients by plants) and was monitored through ammonia and nitrate test kits, these tests were done twice a week. Enclosures allowed for 0.5 pounds (227.0 grams) fish per gallon (3.79 liters) (Rakocy et. al 2006). Temperature of water varied between the two fish species, but was not set to go below 72^{o}F nor above 85.0^{o}F (22.2 to 29.4 °C). In addition to testing for nutrient content; water temperature, dissolved oxygen, and pH were tested every day. Water quality was tested using API Freshwater testing kits (Metacalf, 1991) were used for ammonia, nitrite and nitrate. Dissolved oxygen, pH, and water temperature were measured every day using the Extech DO700 Portable Dissolved Oxygen Meter Kit.

Four tanks were used, each of containing 10 fish from one species, making a total of 20 fish per species. Fish were fed 1.0g twice daily. Each tank supported 14 lettuce plants. The lettuce was grown from seed for one week, before being placed into the system. Each plant was grown for 49 days, at which point it was harvested and weighed.

Results

Tank temperature (degrees Celsius) for both species showed to be stable over the period of the experiment. Figure 1 shows the average of concentration of ammonia, nitrite (measured in ppm) and pH level in the tilapia tanks, over this 64 day period. Figure 2 shows the average of concentration of ammonia, nitrite (measured in ppm) and pH level in the Koi tanks over this 57 day period.

Figure 1: Average of pH, ammonia and nitrite concentrations for Tilapia.

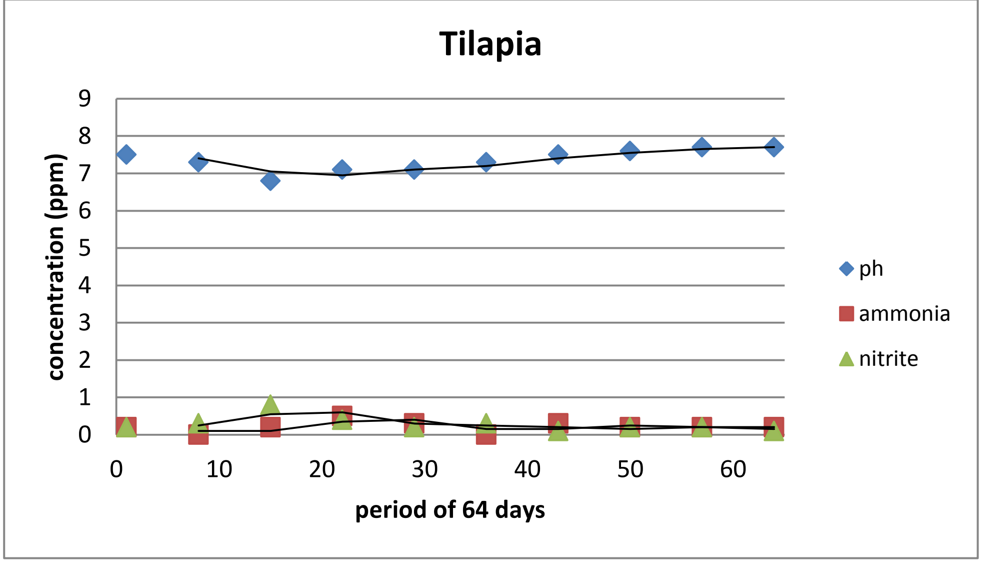
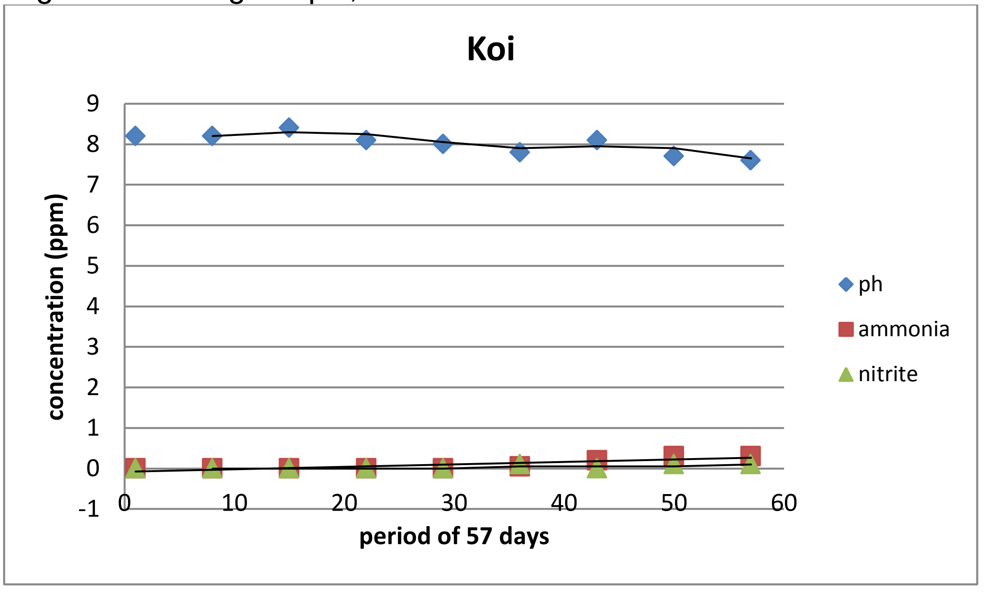


Figure 2: Average of pH, ammonia and nitrite concentrations for Koi.



Carbon Emissions and Electric Usage

To determine the carbon emission the EPA's data of electricity composition during 2009 was used to determine carbon emissions from energy. The total amount of electricity the equipment used during the project was 25.664 kWh/day and Table 1 shows the total electric cost of both systems over the duration of the project.

Table 1: Total electric cost of both systems over the duration of the project.

The Total electricity cost for Koi system	$210.65
The Total electricity cost for Tilapia system	$236.52
Total overall electricity cost	$447.17

Table 2 shows the average of length and weight change in Tilapia and Koi over the duration of the project.

Koi were in culture for 57 days, while Tilapia was in culture for 64 days. This means that the Koi used 1,462.848 kWh or 1915 tonnes of CO_2, while the Tilapia used 1,642.496 kWh for a total of 3,105.344 kWh or 215 kg of CO_2. The cost of a kWh from the months was averaged to $0.144 per kWh when the electricity was charged at commercial price (NYSERDA, 2013). This was multiplied by the total kWh used in each of the systems with the Koi and Tilapia.

In addition, the number of hours spent working on the system were calculated to the minimum wage ($7.25 an hour) with around 15 hours of work being done a week plus the fish feed ($50.00). This was about $1,437.08 worth of labor on all of the systems. Including electricity and other money spent, this was around $678.42 for Koi and around $758.66 for Tilapia systems. This can also be seen as $33.92 per Koi out of the surviving 20, and $42.15 per 1 Tilapia out of the surviving 18. While Tilapia were acquired for free, Koi cost $160.00, thus brought their total cost up to $838.42, or $41.92 a fish. This brought the cost of the systems together, including all costs, up to $1,597.08.

Feed Consumption, Fish Growth, and Carbon Footprint

Table 2: Length and weight change in Tilapia and Koi over the duration of the project.

Average weight for Tilapia (tanks 1A 1B)						**Average weight for Koi (tanks 2A 3A)**					
First day			**Last day**			**First day**			**Last day**		
Fish	Length (cm)	Weight (g)	Fish	Length (cm)	Weight (g)	Fish	Length (cm)	Weight (g)	Fish	Length (cm)	Weight (g)
1	16.5	103	1	20.1	195	1	10.1	15	1	14	49
2	21.5	194	2	22.5	239	2	9.8	13	2	11.4	26
3	17.2	108	3	21.5	203	3	9.4	12	3	14.4	55
4	20.15	159.5	4	22.2	234	4	9.95	16	4	14.1	53
5	19.6	146	5	20.5	150	5	10	17	5	14.8	58
6	18.8	116	6	19.1	162	6	10.4	18	6	13.1	43
7	17.2	99	7	19.3	104	7	9.2	13	7	12.65	39
8	17.8	113	8	20.6	177	8	9.5	13	8	11.7	25
9	20.1	154	9	22.0	163	9	9.9	15	9	11.8	28

10	14.9	66	10	18	130	10	9.6	14	10	13.2	37
Total		**1258**			**1757**	**Total**		**146**			**413**

Overall, Tilapia had a combined weight gain of 998 g with a pellet consumption of 1,692.730 grams. Tilapia growth produced 215 kg of CO_2 or 2.2029 x 10^-10 CO_2 tonne /tonne fish.

From this we can find the Feed Conversion Ratio (FCR), this showed the amount of food units required to grow a unit of fish mass:

FCR = Amount of food fed / amount of fish weight gain
FCR = 1,692 kg / 998 g
FCR = 1.70

Koi had a combined weight gain of 534 grams with a pellet consumption of 800 g and produced 191 kg of CO_2 or 3.6269 x 10^-10 tonne CO_2/tonne fish. The Feed Conversion Ratio (FCR) is the amount of food units required to grow a unit of fish mass (USAID, 2011):

FCR = Amount of food fed / amount of fish weight gain
FCR = 800 g / 534 g
FCR = 1.50

Caloric Content and Lettuce Cost

The amount of calories consumed by Koi from the 800 g of feed was 2,640.616 kcal, or on average, every gram of food consumed was 0.199 kcal. The amount of calories consumed by Tilapia from the 1,692 kg of feed was 4,354.743 kcal, or on average, every gram of food consumed was 0.224 kcal.

The caloric content of 55g of lettuce (rex var.) equals 7 kcal= 7kcal/55g= 0.127 kcal/g (SELF Nutrition Data, 2013). Table 3 shows the total kcal produced in the form of grams of lettuce from each system.

Table 3: Kcal produced in grams of lettuce from each system.

	Koi systems		**Tilapia systems**	
Harvest	Tank 3A	Tank 2A	Tank 1A	Tank 1B
1	256	218	266	419
2	391	240	285	485
3	433	360	268	631
4	233	167	129	232
5	208	125	49	203
6	48	34	25	46
Total	1569	1144	1022	2016
Total kcal	199.68	145.60	130.06	256.57
Total kcal	**345.28**		**386.65**	

Local price of lettuce from local hydroponic growers is $3.29 a head. The heads of lettuce that reached a harvestable date of 49 days was 28 heads for Koi and 28 heads for Tilapia. A potential $92.12 could be sold from both systems, with a total of $184.24.

Discussion

Fish excrete ammonia that is toxic at high concentrations. Bacteria convert the Ammonia to nitrite and then to nitrate; which is non-lethal to fish unless at extremely high concentrations. These processes are further shown below.
Ammonia-oxidizing bacteria of the genus *Nitrosomonas* obtain energy by catabolizing un-ionized ammonia to nitrite (Metcalf and Eddy, 1991):

$$NH_3 + CO_2 + 1.5O_2 \rightarrow NO_2^- + H_2O + H^+$$

Nitrite-oxidizing bacteria of the genera *Nitrobacter* then convert nitrite to nitrate for energy (Metcalf and Eddy, 1991):

$$NO_2^- + CO_2 + 0.5O_2 \rightarrow NO_3^-$$

Nitrate is a nutrient that is at the end of these reactions. It is removed from aquaponics system via plants, which use it to grow. Plants which take up large amounts of nitrate are beneficial to use in this system. Plants that produce leafage as their edible portion are used because they have an affinity for nitrate. However, these processes consume oxygen and releases hydrogen ions and thus lowers the pH of the water (Metcalf and Eddy, 1991). In order to maintain a stable environment calcium carbonate ($CaCO_3$) is added to lower the pH (Ryan, 2007). Normally, the pH of a system would decrease as the system continues without an influx of calcium carbonate, as can be seen in the Koi tanks pH represented in Figure 2. However, in the Tilapia tanks (Figure 1), there is a noticeable increase in the pH. The reason behind this is that excessive ammonia concentrations were being treated with constant water replacement. The water used to replace water in the tanks was tested at a pH of 7.3. Furthermore, limestone already present in the grow bed may have acted in conjunction with the water replacements by increasing the pH. Future uses of this system should ensure proper fish to grow bed ratios, if grow beds are not large enough to handle fish waste influx, pH can change rapidly resulting in stressed or sick fish (Ryan, 2007).

In Tilapia systems, the ammonia concentrations most likely have the most negative effect on the fish health. Other factors such as temperature, nitrite concentrations, and pH can be ruled out as they were within their respective ranges of fish safety. Figure 1 proves this by showing ammonia concentrations for both tanks of tilapia, was over the recommended 0.02 ppm for Tilapia care (Popma and Masser, 1999). Comparing the feed consumption of Tilapia and Koi it was shown that Tilapia feeding remained stagnant (even taking the fish deaths in Tank 1A into account), while Koi consumption of food continued to increase. This could be correlated to the fact that ammonia levels were too high (Figure 1), causing stress, resulting in the Tilapia's loss of appetite. This stress can also cause a disrupted immune system allowing for fish to become more susceptible to disease (Rottmann, Francis-Floyd, and Durborow, 1992). On day 32 for the Tilapia systems, it was noted that fish showed signs of inability to maintain proper buoyancy. This was distinguished by fish floating to the water surface on their sides, to which they would constantly correct via swimming back to the bottom of the tanks. The causing agent was expected to be *columnaris* disease as past uses of the system have seen onsets of this disease in tank culture. Although, lesions (common to this disease) were not observed on affected fish bodies (Durborow et al., 1998). Salt treatments were applied to fish suffering from suspected bacterial outbreaks, in order to help combat the disease. A salt treatment was given on day 35, 40 and 54 of 30 grams salt per liter of water (Masser and Jensen, 1991) to all of the fish in each system. The fish were allowed to sit in the salt water treatment for approximately 1 hour, whereupon they were returned to their tanks and were monitored twice a day during normal feedings (Masser and Jensen, 1991). While this method proved effective in preventing a large scale die off in the systems, two fish died one on day 37 and the other on day 57. This may be the reason why there was a decrease of pellet consumption on those days for Tank 1A

In comparison, the Koi systems both ran smoothly (with the exception of temperature), until near the end of the project. The fact that the temperature remained mostly around 28°C instead of 22°C may have suppressed their feeding and growth (Craig et. al, 2004). A steady incline in the amount of pellets consumed was related to Koi growth. Towards the end of the project ammonia and nitrite concentrations were going past recommended levels of .05 ppm. If the project continued, future results may have caused a decline on feeding and an increase of sickness.

A large portion of this project was looking at the inputs and outputs of this system. The amount of calories consumed by Koi was 2,640 kcal, while the amount of calories consumed by Tilapia was 4,354 kcal. Koi systems produced 345.28 kcal of lettuce while Tilapia systems produced 386.65 kcal of lettuce. This demonstrates how the amount of energy into a system can be reduced as it goes through different organisms. To further this study, the fish would have to be harvested and the amount of calories contained within their meat would have to be analyzed and the kcal calculated.

Another part of this project was to look at the amount of CO_2 created from the running of the systems. The amount of CO_2 produced from the growth of Koi, as demonstrated by this system, was 3.6269×10^{-10} tonne CO_2/tonne fish. The amount of CO_2 produced from the growth of Tilapia was 2.2029×10^{-10} CO_2 tonne /tonne fish. This correlates to a recent paper that herring, with one of the lowest amounts of CO_2 when fished, produces 1.2 x 10-6 tonne CO_2/tonne fish (Sonesson et al., 2010) by the time it gets to a consumers plate. Fish such as cod and salmon showed 3.8 - 4.8 CO_2 tonne /tonne fish and 1.8 - 4.2 CO_2 tonne /tonne fish respectively (Sonesson et al., 2010). Another study showed that small pelagic fish (capelin, herring, blue whiting, sandeels, mackerel sp., and Atlantic menhaden) create around 200 kg CO_2 /tonne fish by simply being brought to shore and not including outputs in order to bring it to the consumers plate (Tyedmers, 2001). This study demonstrates that aquaponics systems may be more beneficial to the environment than conventional fishing as they produce lower amounts of CO_2 while also producing edible plants. However, in order to get a more complete CO_2 output from these systems, the amount of CO_2 used from heating the greenhouse and the amount of CO_2 produced from creating and shipping the fish feed should be further investigated.

The feed conversion ratio for Koi was 1.5, while the feed conversion ratio for Tilapia was 1.7. Koi were more efficient than Tilapia at converting the feed into fish growth. However, Tilapia converted more food into fish weight than Koi did. As such, the feeding rates, and feed conversion ratios were most likely affected because fish metabolism and growth rates may vary by size and age. In addition, Tilapia were larger than the Koi from the start of the project, which may have skewed comparing the fish outright. It is for this reason that a study should be conducted over a longer span of time to negate variables of fish growth dependent on fish age and size.

Including electricity, maintenance, and other money spent, this is around $838.42 for Koi and around $758.66 for Tilapia systems during their run times. This can also be seen as $41.92 per Koi out of the surviving 20, and $42.15 per Tilapia out of the surviving 18. If the tilapia were sold, they would be worth $4.49 per pound (Fisherman's Cove Seafood, 2013). When filleted, it could be estimated around 3 pounds or $13.47 would be sellable (Fisherman's Cove Seafood, 2013). During the project, Koi did not grow enough to gain value, as they were bought at $160.00, they did not reach the next size range for sale (Blackwater Creek Koi Farms, 2013). Furthermore, a potential of $92.12 in lettuce was grown from both Koi and Tilapia systems. Taking this into consideration the cost for raising all Koi was $746.30 and around $653.07 for all Tilapia. This can also be seen as $37.32 per Koi out of the surviving 20, and $36.28 per Tilapia out of the surviving 18. In the end, for this project, both fish would leave the grower in debt as there was a cost associated with the fish instead of a potential surplus. This being said, Koi did well for being grown on a diet that wasn't designed for their metabolism, as its diet should consist of Koi food which requires 25 - 32% protein (Craig et. al, 2004). However the feed used contained a protein content of 36% and 45%. Furthermore, Koi were bought at $6.50 a fish, given that they are still in the 4 - 6 inch growth range while some of the most expensive varieties of the same size can be sold for $31.90 (Blackwater Creek Koi Farms, 2013). Finally, these systems were not run at full capacity, as an additional 1-2 grow beds per fish tank could be used and provide 2-3 times the profit off of lettuce. Future studies should use a more correct ratio of fish to grow bed area, run longer, and be repeated in order to prove these results to be accurate or not. Furthermore, in the aquaponics businesses, fish are often grown to a certain size in tanks together, and then split into other tanks as tanks reach full capacity for the amount of fish. This would lower costs by not having to run more pumps, heaters, lights, and aerators.

Many of the variables in this study do not allow for complete comparisons of the data to each other. It is therefore necessary to see the plausible outcomes of aquaponics systems in repeated experiments such as these run in better-conducted economical models and to verify accurate results. While Tilapia show promise to produce less CO_2 than the average company harvesting fish, Koi have more of a market value because they can be sold for more by length instead of by pound. This allows for Koi to have a potentially much higher sale value than Tilapia and still be able to provide the nutrients required to grow lettuce for profit.

Conclusions

Aquaponic systems most often function as system that provides food from both fish and vegetation. This project was meant to determine the benefits and downfalls of growing an ornamental fish compared to one used for food. The project was to look at all energy inputs (kcal, kWh, feed conversion ratio) and all outputs (lettuce growth, fish growth, CO_2 released) in order to see which systems were better economically and to compare the CO_2 output of fish for consumption verses industrial fishing practices. The projects main focus was a cost/benefit analysis of ornamental fish verses fish used for food grown in an aquaponics system. Our study showed that fish of ornamental value, such as Koi have a higher selling price and can still produce enough waste to grow lettuce for additional profit. Furthermore, Koi had better feed conversion ratios than Tilapia, indicating that their cost of food may be less because they are better at converting food to growth. However, it is still possible for Tilapia to grow faster than Koi and have worse feed conversion ratios. Lettuce production could have been 2-3 times the amount in these systems as systems should normally have 2-3x the grow bed area that this project ran on for the amount of fish grown. For future studies it would be intriguing to grow fish from a food source that does not have a CO_2 cost, and is created from a source that reuses resources like post-consumer food waste. This would drive CO_2 output down compared to a fish grown on store bought pellet feed.

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