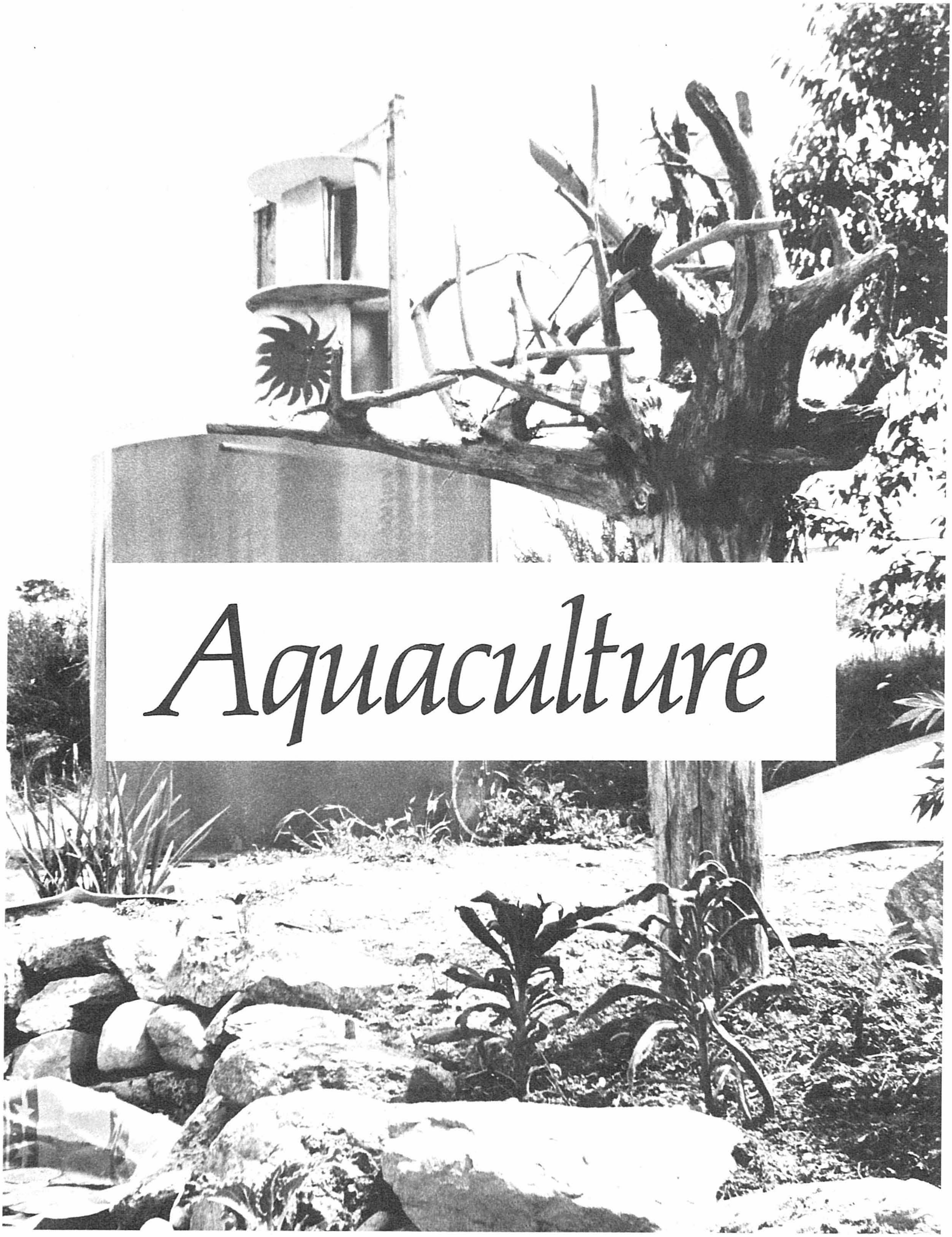
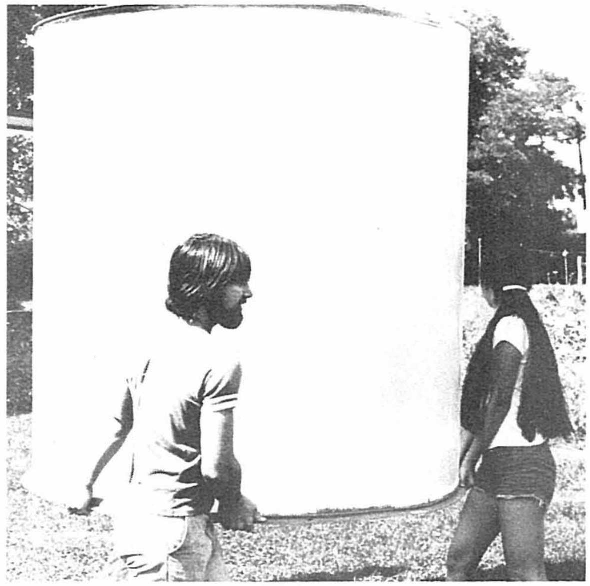
Aquaculture





In spite of ongoing efforts on all fronts, our real news this year has come from the work in aquaculture and bioshelters. About two years ago, John Todd had an idea for the creation of what we have come to call "Solar-Algae Ponds." These are translucent cylinders which allow the interaction of algae with light on all pond surfaces except the bottom. They are proving far more productive of algae and consequently of fish than we had anticipated. Ron Zweig describes working with them in the article called, "The Saga of the Solar-Algae Ponds." We see potential applicability for them in the fact that the cylinders are economical in terms of cost and space and can be used inside and out, in urban, suburban and rural areas. Our other semi-closed aquaculture projects in established systems are described and contrasted in Ron's other articles.

Meanwhile, Bill McLarney, when he can be lured back from Costa Rica, is directing his attention to "Cage Culture." It seems, as he explains, a practical direction for people who have access to standing bodies of water. As a major limitation on fish raising is the high cost of fish feed, much of his effort and thinking is toward the search for alternatives to commercial fish food. His first summer's work is summarized in "Cage Culture."

The Saga of the Solar Algae Ponds

– *Ron Zweig*

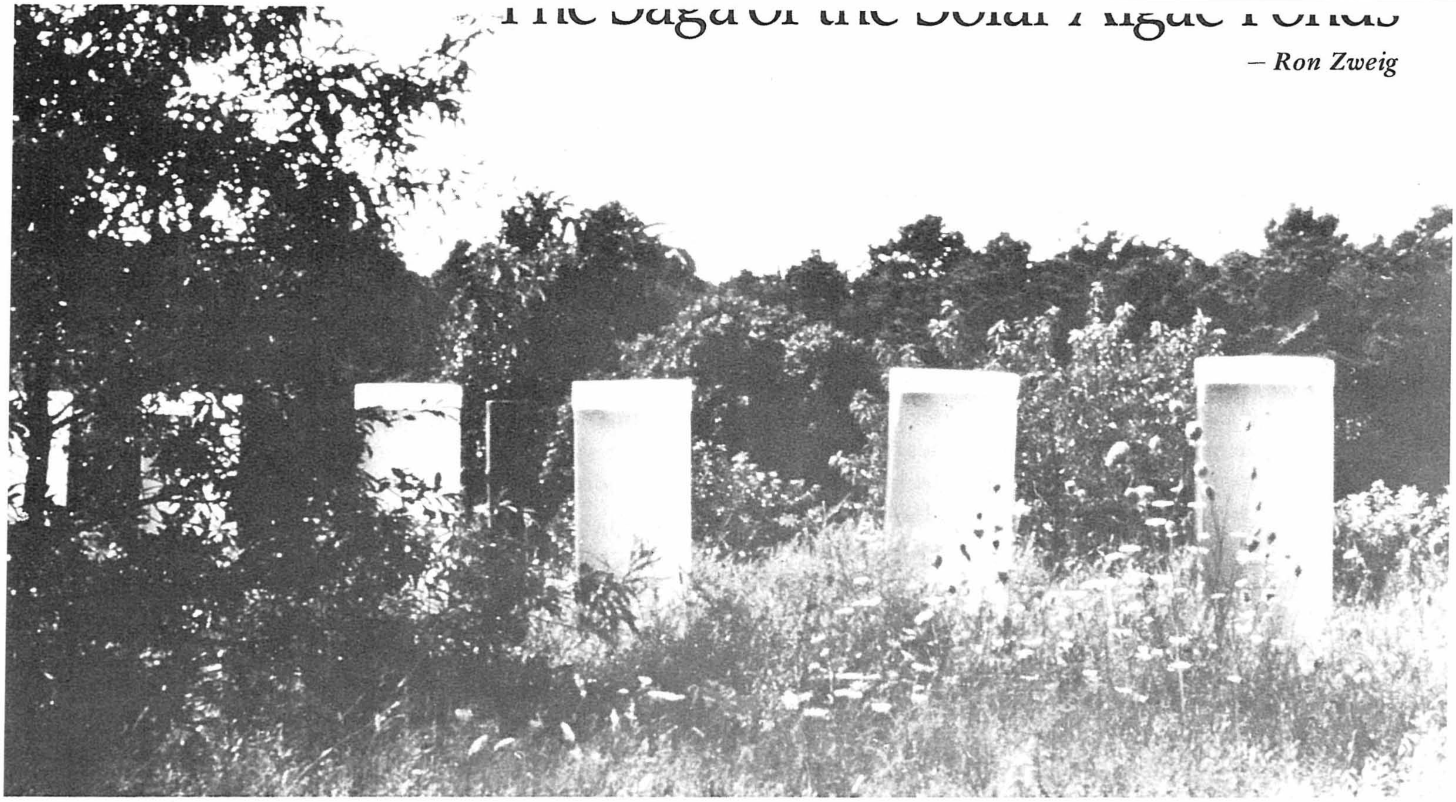


Photo by John Todd

The development and use of Solar-Algae Ponds is the latest innovation in New Alchemy's aquaculture. These ponds which are in themselves semi-closed ecosystems are cylindrical tanks made of highly translucent fiberglass. They have a depth and diameter of 1.5 meters (5 feet) and contain up to 2.78 cubic meters (734 gallons) of water. They were constructed by the Kalwall Corporation at approximately $150.00 per pond. We have also experimented with tanks of the same material, with a depth of 1.5 meters but having a diameter of approximately 0.45 meters. The fiberglass material is .06 inches thick and is expected to last twenty years.

Pond Theory and the Algae Component

The theory behind experimenting with these ponds was to increase the amount of pond surface area exposed to solar energy. With these tanks, not only is the upper surface exposed to light penetration, as in a conventional pond, the sides of the tank are as well. This has proved a most effective means of collecting and storing solar energy, especially in northern latitudes, when during the winter months the sun's position in relation to the horizon is quite low and the low angle rays can penetrate the water mass. The same would hold true for complementary southern latitudes.

The tanks can be used both outside and inside structures including ordinary houses. A number of tanks can be linked together to form a "Solar River." Both the Cape Cod and Prince Edward Island Arks have been designed with this in mind. Some of the linked ponds could be used as fish polyculture tanks, others as filtering components, and still others as zooplankton production ponds. Water can be transferred between them using an air lift pump. It has been found that air bubbled into a narrow tube can lift water one-half the depth of a pond. This air could be provided by an air compressing windmill and could be stored in pressure tanks. One-half pound of air pressure is required for each foot of depth. An initial pump of this type would be required and then the water would be cycled through the other ponds in the "river" by the use of siphons.

The phytoplankton population in these ponds can become extremely dense, due to the high quantity of light entering them. Last winter at Yale University, John Goldman used a small solar pond to experiment with Tilapia and the phytoplankton that grow in our systems. The predominant species was the Chlorococcales *Golenkinia* sp. This alga is a small spherical cell with thin spine-like structures extending in all directions, which give it pelagic capabilities. Since water movement within an independent pond is restricted to the stirring caused by the swimming of the fish, characteristics such as those of the *Golenkinia* sp. are necessary to keep the algae from settling to the bottom. In addition to *Golenkinia* sp., some *Scenedesmus* sp. and a few other algae species were also found. The functions of phytoplankton in these systems are listed in the description of the Miniature Ark.

Goldman found that the population densities of *Golenkinia* increased logarithmically in a proper nutrient medium. In some trials, bacteria populations were established prior to the algae, preventing the algae from blooming. This supports the hypothesis that bacteria compete with phytoplankton. When Tilapia were introduced into algae-rich systems, they were found to crop back the population through filter feeding. A transparent cylindrical culturing system has been used by Cook, consisting of a pyrex glass tube 4 inches in diameter and 6 feet in height. He cultured the Chloroccocales *Chlorella pyrenoidosa* which he calculated to be capable of using 2.5% of the incident solar radiation. He harvested his culture regularly, however, replacing it with nutrient-rich medium as desired densities were achieved. Both Goldman and Cook used artificial light to drive their cultures continuously.

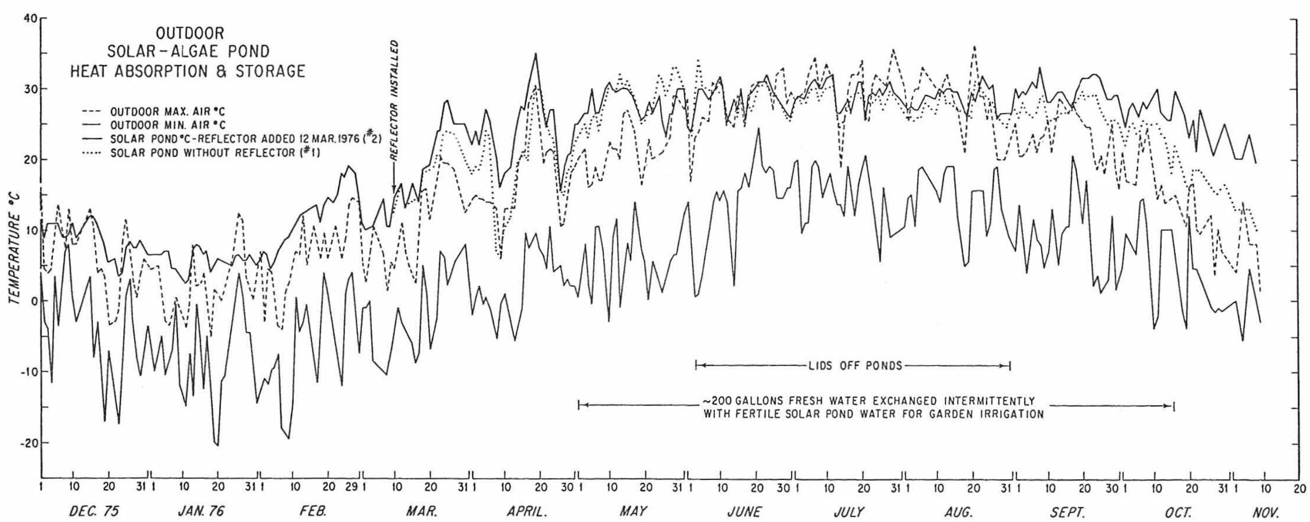
Goldman found that with his *Golenkinia* sp. cultures at an average temperature of 29°C, *Tilapia aurea* grew 0.1 grams per day. Phytoplankton alone does not provide optimal growth. It does provide enough food for maintenance and a little growth. Another alga such as *Spirulina platensis,* which is discussed in the Miniature Ark section, might improve production. For specific questions regarding Goldman's data, please write to us.

Winterization

The outside solar ponds required several adjustments for winter. A second layer of fiberglass was added to the outside vertical wall of the cylinder. This was done by winding garden hose 1.6 cm (5/8 inch) in diameter as a spacer around the top and bottom of the pond. Then a second layer of fiberglass was tightly wrapped around the spacer and sealed with clear silicone sealant, creating a thermal pane. Thick styrofoam insulation 5 cm (2 inch) cut in a 1.5 meter diameter disk was placed beneath the pond. A small, double-layer geodesic dome 1.5 meter-base diameter was placed on the upper perimeter of the cylinder. Insulated in this way, the outside tanks maintained the highest temperatures of all our aquatic systems including those within the other solar-heated structures. During the '75-'76 winter, the Miniature Ark, Dome and Six-Pack Ponds fell to freezing, whereas the Solar-Algae Ponds were measured at 4°C with the outside temperature at -21°C. A temperature profile of these ponds with maximum and minimum outside air temperatures is found in Graph 1. The '75-'76 winter was not particularly cold, however, there were short periods of intense cold for Cape Cod, as indicated by the chart.

On March 12, 1976, a parabolic reflector was installed behind Solar-Algae Pond No. 2 which was outside. It was focused on the center of the pond. The reflector was constructed of five vertical, ten-foot 2 x 4's, placed four feet apart and buried two feet in concrete. Four 4' x 8' quarter-inch reinforced sheets of plywood were bolted to the studs, long edge up and braced on the north side. The 128 ft^2 of surface area was covered with a reflective metalized polyester laminant attached with duct tape. This attachment method was used to allow for the possibility of detaching it, in the event of the loss of reflectivity, and turning it around to use the other side, as both sides are reflective. This has not been necessary. The first side is in excellent condition as of this writing (Winter '77). The material was made by the Hy-Sil Manufacturing Company of Revere, Massachusetts.

To construct the parabolic arc a line was defined equidistant from a given point and straight line (see Diagram 1). In this case, the point was the center of the pond and the straight line ran east and west, ten feet north of this point. During the spring, the difference in temperature between the pond with the



GRAPH 1.

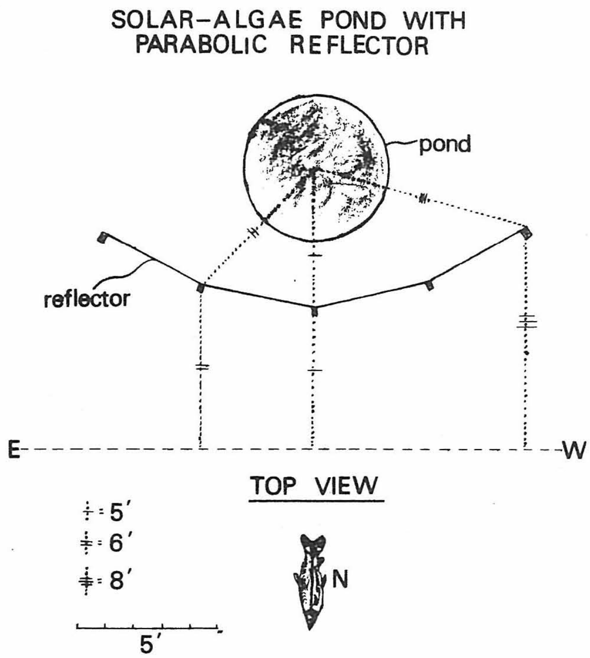


Diagram 1.

reflector (Solar-Algae Pond No. 2) and the one without (Solar-Algae Pond No. 1) was approximately 4°C. The reflector's position to the north of the pond provided a good wind break from the cold north winds. On a sunny day, Solar-Pond No. 2 was capable of an increase in temperature of 4.5°C) (≃ 8°F) which amounts to an increase of 12,510 Kcal (49,000 BTU's) for the 2,780 kg (6,123 pounds) of water in the pond. The tops were left on the tanks throughout this period. Energy studies are also being done with the solar ponds inside the Cape Cod and Prince Edward Island Arks.

There is an advantage to building a vertical reflector. It provides excellent reflectivity on the pond during the winter months when the sun is low in the sky yet less effective during the summer, especially around the summer solstice, when added heat is unnecessary. The sun is then very high in the sky and most of the direct sunlight striking the reflector is deflected to the ground on the space between the pond and the reflector. The intensity was very concentrated – strong enough to melt the styrofoam extending beyond the base of the pond. The ponds reached optimal Tilapia growth temperatures of 26° to 36°C during the summer with the tops removed.

The reflector became more effective as the sun sank in the southern sky during July and August. Overheating can become a problem, however. If so, the reflector can either be removed or masked with tall plants. This year, unintentionally, several plants, including lamb's-quarters, which usually grow waist-high, grew to two meters between the pond and the reflector. The phenomenal weed growth was probably because of the plants receiving light from all sides while being protected from the wind. Dwarf fruit trees in moveable boxes could be used for selective shading when necessary. The outdoor solar pond design is being explored further and will be expanded to include about thirty solar ponds in a reflective courtyard adjacent to the Cape Cod Ark.

Outdoor Experimentation

Over the past year, we completed six fish production trials, using the larger 1.5 meter diameter ponds and one series of experiments using the 0.45 meter ponds coupled together.

Coupling and Density Experiments Using the Smaller Solar Ponds: The first trials with linked solar ponds were done last summer. Sixteen of the smaller ponds were used, connected in eight individual couplets. Water flowed between them continuously. It was pumped by a simple air pump device over into the adjacent tank (see Diagram 2) and flowed back through a siphon. The rate of flow varied because the screens on the ends of the exchange tubes became clogged with growing algae, necessitating repeated cleaning. The screens were necessary because the size of the fish used in the experiment was so small that they swam through the tubes to the adjacent pond. This experiment was designed to test the efficiency of fish growth at different numbers per volume of water. Three densities were tested – one fish per gallon, one fish per two gallons and one fish per four gallons. The one fish per gallon experiment was duplicated with filter screens of crushed oyster shells glued to sheets of fiberglass which were hung in the tanks. Densities were tested in two ways. In the first, all the fish were in one of the coupled ponds. In the second, the fish were evenly divided between the two. The two ponds

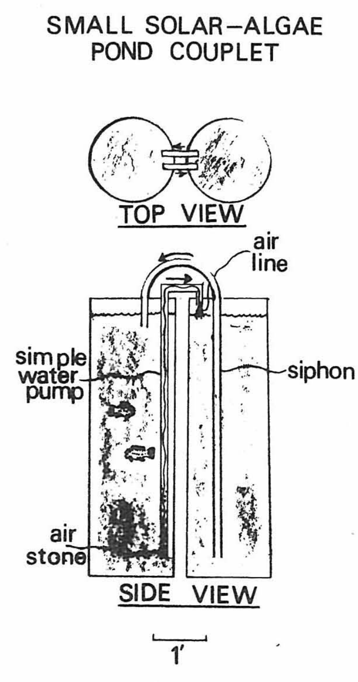


Diagram 2.

together contained a maximum of 132 gallons of water. In the first instance, 130 fish were placed in one of the ponds and, in the second, 65 were put in each of the two.

The results are preliminary and not sufficient to draw definitive conclusions without further trials in terms of density efficiency; however, some useful observations were made. With respect to growth, of all the New Alchemy experiments, the greatest mass per unit volume or surface area was produced in these small ponds. The fish used were small, weighing about 0.1 gram each. Twice daily, six days a week, they were fed 3% of their total body weight of Purina Trout Chow per pond. They grew to a maximum of 361.25 grams in one of the systems. The average ratio per couplet of wet fish to dry feed was 2.14 with a maximum of 3.59. These high efficiencies are probably due to the small diameter of the ponds, which increases the intensity of solar radiation per unit volume of water, resulting in more efficient photosynthesis and high algal production and oxygen levels. As the phytoplankton absorbs the entering light in larger systems with high algal densities, there would be a limitation of photosynthesis in the internal area of the tanks.

The design of the experiment demonstrated several phenomena about coupling the tanks. In the cases of the couplets with fish on one side, a build-up of sediment occurred in the complementary tank which fouled the water and raised levels of such toxins as ammonia. This was due to a lack of stirring of the sediments. The ponds with fish on both sides remained healthy with the exception of the trials with one fish per four gallons of water. The fish in these ponds probably were neither large nor numerous enough to stir the sediments sufficiently. Balances must be carefully worked out. If the couplets with the fish isolated on one side prove most efficient, a stirring method must be developed. Crayfish possibly could be used in the bottom of the fishless ponds to keep the bottom stirred or the sediments could be removed through periodic siphoning.

In the pond containing 130 Tilapia on one side, *Simocephalus* sp., a Cladoceran, bloom occurred. This was the first zooplankton bloom in one of these ponds. The sediment build-up was considerable at the time of the bloom which may indicate that potentially unhealthy conditions for the fish may be necessary for a good zooplankton population. Raising zooplankton as fish feed is another parameter to our Solar-Algae Pond research. This may lead to independent ponds for independent functions.

Production Experiments

Experiment 1 – Winter Trials: The two 1.5-meter outdoor Solar-Algae Ponds containing temperate species of fish were used. These included Israeli carp, Chinese Big Head carp and Chinese Silver carp. All the fish died in one of the ponds, probably because of the release of lethal copper ions from a bronze air valve which, undetected by us, fell into the pond.

Solar Pond No. 1, however, remained viable and productive. On November 28, 1975, 11 Israeli carp weighing 875 grams were introduced. On December 9, a twelfth was added at 125 grams, making a total weight of 1,000 grams. On December 1, 40 Chinese carp were added weighing 85.2 grams. On April 8, 1976, the 12 Israeli carp were removed, by then weighing 1,750 grams. The 34 surviving Chinese carp weighed 180 grams – a total increase of 844.8 grams. During the course of the experiment, the fish were fed 2,880 grams of Trout Chow and 96 grams of TetraMin, making a total of 2,946 grams of feed. The wet fish to dry feed ratio was 0.29 to 1.0. Although this was low, it demonstrated the viability of the tanks. During the course of the experiment, temperatures were quite low, during some periods just above the lower lethal limit. The trial was not a highly productive period in terms of fish mass gained, but it did demonstrate that the fish could live and grow in these ponds.

Experiment 2 – High Density Polyculture: The first warm weather experiment was intended to determine the maximum number of fish that could live in a single tank. Over the winter, 146 Tilapia were kept in a small 66-gallon solar pond in the house, totaling 2.2 Tilapia per gallon at 20°C. The number of fish put into Solar Pond No. 2 was 247 Tilapia at 3,995 grams, 13 Israeli carp at 1,950 grams and 34 Chinese carp at 180 grams, a total of 344 fish at 6,125 grams. The fish were added between April 8 and May 4, 1976. The last 54 Tilapia were added on May 4. May 7 was a dark, cloudy day resulting in oxygen levels too low to maintain the population because of insufficient solar energy to drive the photosynthetic process. As a result, on May 8, six Israeli carp at 775 grams, 45 Tilapia at 960 grams and one silver carp at 4 grams were discovered to be dead and removed. A mechanical back-up aeration system was added, but it failed on the night of May 9. The following day, 19 Chinese carp at 140 grams and one Israeli carp at 190 grams died and were removed. The water temperature rose to 30°C on May 10. The aeration was continued throughout the experiment.

Several times during the experiment, ammonia concentrations were quite high – up to six parts per million. (Less than one part per million will kill rainbow trout).* Supplemental feeding was halted

* Robinette has found that sub-lethal levels of ammonia at 0.12 – 0.13 ppm will inhibit channel catfish growth which he found to die at about 2.0 ppm. Therefore, although the fish in our experiment can withstand high levels of ammonia for a period of time, their growth could be strongly inhibited with these concentrations.

and between one-quarter and one-third of the water in the tanks was changed daily by siphoning waste water from the bottom of the tank. The water was used to irrigate parts of the garden. It was replaced with tap water. The process was continued until ammonia concentrations were reduced. Generally, it is a good practice to dilute once a week any chemical factors which could arrest fish growth or could be dangerous to the fish. During this trial, we pushed the viable limits in terms of feeding and population density.

The experiment was completed on July 15. The entire population increased in weight by 6,980 grams. During the experiment, 6,675 grams of Trout Chow, 101 grams of TetraMin and 175 grams of soy flour were fed to the fish, resulting in a wet fish to dry feed ratio of 1.0 to 1.0. This includes the dead fish which were removed. The fish were fed a supplement of *Azolla, Hydrodictyon* and *Lemma.* The tank had a rich phytoplankton bloom. These were not measured quantitatively.

Experiment 3 – Zooplankton Culture: While this experiment was in progress, Solar Pond No. 1 was inoculated with large populations of indigenous zooplankton caught from a local pond. This was done to try to grow populations of zooplankton in a solar pond as supplemental fish feed. The initial attempt was not successful. Although there was a good phytoplankton bloom in the pond, the water chemistry, nutrient balance or temperature were not suited to the small animals. Inoculations were made twice weekly from April 8 to May 14.

Experiment 4 – Tilapia Breeding: Six of the largest Tilapia were put in Solar-Algae Pond No. 1 on May 14. This was done as a breeding experiment to find whether the Tilapia would breed in this type of pond. In addition, we hoped to use their progeny to select for a fast-growing population. The fish weighed 475, 375, 350, 200 and 150 grams or a total of 1,550 grams. As of July 7, there was no evidence of reproduction, leading us to question whether all the fish were either male or female. Tilapia mating behavior requires the male to prepare a cleared spot against a dark object or surface. Because of the translucent sides of the ponds, a male backing against a surface would back into the light. This could disrupt mating behavior or limit it to night activity. In addition, the fish can see people walking past the tanks and become startled. Tilapia mothers have been known to swallow their brood if sharply disturbed. Reproduction could possibly have been arrested by a periodic striking of the side of a tank. Moriarty found that disturbing the *T. nilotica* caused inefficiency in their digestion for a time.

To help eliminate these variables and provide a breeding area, on July 7 two concrete blocks were placed in the tank and a piece of black polyethylene was wrapped around the lower half of the north side. On July 29, three weeks later, the first young Tilapia were seen, of which only three were netted out. These were the only young fish found even with further masking of the lower half of the south side on August 4. These tanks cause serious reproduction retardation if not failure. Further research is required.

The experiment ended November 9. The fish were fed a total 6,700 grams of Trout Chow Floating Pellets. The fish grew 3,550 grams with a conversion ratio of 0.53 to 1.0 wet fish to dry feed. There was a total of 20 fish – 14 young from breeding activity.

The largest fish weighed 1,100 grams (2.42 pounds). The fact that the fish grew so large demonstrated that the size of the ponds does not limit fish growth. In fact, the fish achieved a weight nearly five times larger than we feel necessary for useful production. The low ratio of food conversion is probably due to a lowering in growth efficiency with the larger fish. We abandoned selecting for a fast-growing population in Solar-Algae Ponds because it might result in the selection of aggressive characteristics. To do so would require highly controlled conditions with individual fish in individual tanks. That growth potential is a genetic variable in Tilapia has never been demonstrated. Again, work is necessary in this area.

Experiment 5 – Tilapia Monoculture: Beginning July 15, 1976, a second trial was run in Solar Pond No. 2. Two hundred and fifty Tilapia (one per three gallons) weighing a total of 40.5 grams were put into the pond. The fish came from the new population bred in the Dome. They were fed a total of 3,825.5 grams (8.41 pounds) of Trout Chow. The fish grew to 3,480.5 grams or an increase of 3.44 kilograms. The wet fish to dry commercial feed mass was 0.9 to 1.0. This figure is probably due to inability of the fry to assimilate phytoplankton during the early stages of their development, relying, therefore, chiefly on the commercial feed. In nature, *T. nilotica,* another phytoplankton feeder, have been observed by Moriarty and Moriarty (1973b) to be mainly carnivorous until they reach 3-6 cm in size. The mass of fish obtained from this pond will be discussed in regard to the other systems in the summary.

Solar-Algae Pond Summary

The Solar-Algae Ponds have demonstrated phenomenal fish productivity. The smaller ponds, used in couplets, demonstrated the highest productivity. The results, however, were inconsistent. In the two large pond productivity experiments, productivity was excellent. It is necessary to extrapolate the size of the ponds and the time span involved to that of a hectare per year in order to gain comparative figures. Fish productivity is computed in kg/hectare.

The best productivity recorded in pond aquaculture ranges between 1,000 and 15,131 kg/hectare/year, using South China herbivores in fertilized ponds with supplemental feeding (Odum, 1971). In Solar Pond No. 2, in the first trial of the summer, production was the equivalent of 142,840 kg/ha/yr, nearly ten times greater than the best natural pond culture. The second trial at 63,962 kg/ha/yr is nearly five times greater. The difference in the two is probably due to one of two reasons. It could have been because four different species of fish were cultured in the first trial and, in the second, a monoculture of Tilapia was used.

The other reason could be that immature Tilapia were used. In the second trial, the young Tilapia were mainly omnivorous during most of the experiment, subsisting chiefly on the commercial feed, whereas, in the prior experiment the fish were older herbivores capable of feeding upon the dense phytoplankton in the tank. It would, therefore, be best in the case of phytoplankton feeders to use fish of approximately six centimeters in length, when they can be mainly herbivorous. They could be bred and grown separately to this size for high production purposes.

The Solar-Algae Ponds are efficient largely because of the high amount of solar energy allowed to enter the pond. This energy drives the photosynthetic process which produces large amounts of dissolved oxygen in the water and increases the primary productivity of the pond, producing dense populations of phytoplankton for food for the Tilapia. Water temperatures and oxygen concentrations are more uniform than in a conventional pond due to the exposure of the entire column of water to light energy.

McConnell has found that the growth of *Tilapia mossambica,* which is mainly a bottom feeder, can be correlated directly to the amount of photosynthesis occurring in a pond. Using opaque tanks with open tops, he computed a linear relationship between the cube root of the mass of growth per individual and photosynthesis. His measure of photosynthesis was based on oxygen production. If this relationship can be extended to *Tilapia aurea,* the efficiency should be greater. Not only would the water chemistry affect the *T. aurea* growth, through photosynthesis, as in *T. mossambica,* it would also encourage greater phytoplankton productivity, a food source for the *T. aurea.* Therefore, due to greater photosynthetic potential, *T. aurea* should grow more efficiently using translucent solar ponds, although normal sub-surface ponds with good phytoplankton populations would also have greater efficiency with *T. aurea.* Our aquatic system demonstrates a direct link between Tilapia growth and phytoplankton photosynthesis.

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Three Experiments with Semi-enclosed Fish Culture Systems

– Ron Zweig

The Miniature Ark

The Miniature Ark consists of a small, experimental closed-loop "river" which courses through three small greenhouses. The water is circulated through the closed system by the pumping action of a sail-wing windmill and a small electric pump. The circular "river" is solar heated, receiving supplemental heat from a solar collector as well as through natural passive heating of its small greenhouse covers.

The water is pumped up from the bottom pool into the upper section where biopurification takes place. It then flows by gravity down into the covered middle pool where zooplankton are cultured as auxiliary fish feeds. These tiny aquatic animals are swept downward with the water on its return to the lowest pond in the loop. This largest and deepest pond houses dense populations of fishes.

The Miniature Ark was designed to test the effectiveness of flow or rapid nutrient exchange and biopurification in a small closed aquaculture facility. Its primary energy inputs are the sun and the wind, which provide light, heat and water flow. The Miniature Ark, as originally designed, was described by McLarney and Todd in the second *Journal of the New Alchemists*. This article chronicles attempts to improve its design as a contained food-producing ecosystem and to increase its productivity.

Redesigning the Miniature Ark's Biological Elements

The first step in the redesign of the biological elements of the Miniature Ark was to change the components of the biological filter. All the shells, plants, earth and barriers between the sub-units in the upper pool were removed completely, leaving only the cement tank. Although the filter had been very effective, there were drawbacks to it. It helped in the conversion of toxic ammonia to nitrates and in the breakdown of fish pheromones. However, because both the nitrifying bacteria and the fish in this system are aerobic, the bacteria compete with the fish for oxygen. Further competition occurs between the bacteria and phytoplankton in the system.

Most aquatic plants, including phytoplankton, compete biochemically. For instance, Murphy *et al.* reported that a species of blue-green algae *Anabaena* produces hydroxamates which chelate iron ions. By binding to the ferric ions in the system, they compete for iron, preventing other plants from utilizing it although it is a necessary nutrient in their diet. Thus, the *Anabaena* is capable of suppressing other populations of algae. This is one example of what seems to be a highly intricate chemical interaction and competition among the plants in an aquatic system. As the interaction includes bacteria, the quahog shells which provide a growth substrate were removed from the pool in the Miniature Ark. The phytoplankton serve four important functions in the system, and their populations should not be in competition with the bacteria. The functions are: (1) Oxygenation of the water through photosynthesis; (2) Food for the *Tilapia aurea* which are phytoplankton feeders; (3) Heating. By acting as microheaters, they absorb the energy of the sunlight as it strikes them, converting some of it to heat energy and warming the water; and (4) Purification. Chloroccocales such as *Chlorella* and *Scenedesmus* are capable of metabolizing ammonia directly and even preferentially to nitrates, as has been demonstrated by Syrett and others. This means they will use all ammonia present before using nitrates. This is interesting because it indicates that the phytoplankton perform at least one of the same functions as the bacteria in the filter. With *Chlorella pyrenoides,* the use of ammonia nitrogen as opposed to nitrate provides a 30% higher efficiency in the use of light energy. Therefore, some phytoplankton productivity is enhanced by the ammonia from the fish wastes. For the first time, we developed an excellent phytoplankton bloom which had a Secchi disc reading of 40 cm or less.

We are still uncertain as to all the functions of the filter bacteria such as pheromone metabolism, in terms of whether or not the pheromones also would be removed through phytoplankton metabolization. The sides and bottoms of the pools in the Mini-Ark are cement, which provides a calcium carbonate substrate for some bacteria, and this may be enough surface area to dilute the chemicals involved in fish density communication.

The removal of the shells eliminated a component thought to be useful in buffering the pH of the water. This, however, would have been a short-lived mechanism according to Spotte, as the shells rapidly become covered with an organic coating which nearly eliminates their buffering capacity. The cement walls also buffer the pH, but they, too, are quickly coated and serve chiefly as a substrate for bacteria and other sessile organisms to grow.

In terms of operation, the chief problems were with low levels of dissolved oxygen and a high population of snails. On cloudy days, the oxygen levels went as low as 0.5 parts per million and, on sunny days, as high as 12 parts per million. The cloudy days induced respiratory stress on the fish, forcing a reduction in feeding and a consequent reduction in growth. The depth of the main polyculture pool is partially responsible. An increased flow rate through splash down between pools, which would oxygenate greater volumes of water, would help. The flow rate varied between 600 and 1,200 gallons per hour, with the windmill and electric auxiliary pump moving up to 600 gallons per hour each. The windmill required good wind conditions to pump 600 gallons per hour.

A large population of snails in the Mini-Ark last summer competed with the Tilapia for both oxygen and algae growing on the walls of the tank. To combat this, we introduced our first specimens of *Cichlosoma labiatum* and *C. citrinella,* two Central American cichlids, which we received from Ken MacKaye at Yale University. They are known snail eaters, whereas the Tilapia eat snails only if they are crushed first.

The zooplankton populations in the middle pool were quite low. There was only an occasional bloom although the pool was seeded several times with indigenous species from a pond adjacent to the farm. This limited animal protein for the fish. As reported by Porter, zooplankton has been found to help in the propagation of phytoplankton. Porter indicated that *Daphnia magna* break up colonies of planktonic green algae but assimilate only part of them, allowing up to 90% of the remaining cells to grow into new colonies, thereby increasing their density. With a greater zooplankton population, a higher concentration of phytoplankton could develop, providing a food source for both the zooplankton and the Tilapia.

This summer's experimentation in the Miniature Ark involved a monoculture of *Tilapia aurea.* One thousand fish were introduced into the 34.5 cubic meter (9,000 gallons) system on 22 June 1976. They were very small (2-3 mm) having hatched in the Dome in preceding weeks. They weighed a total of 150 grams.

The chief supplemental source of food for these fish was Purina Trout Chow. This was to establish quantitative results in terms of ratio between fish mass and feed mass. The trout chow was partially supplemented with crushed snails, mosquito larvae, zooplankton, purslane, marigold flowers, comfrey, soy flour, *Azolla, Hydrodictyon* and phytoplankton (predominantly *Golenkinia*) in the system. Quantitative measurements were not taken from the latter feeds. The vegetative feeds were given to the fish in large quantities starting in late July. Before that, they were mainly carnivorous. The most significant dietary observation made, not only in this system but also in the others, was that the fish chose the highest protein source first. For instance, comfrey, *Symphytum,* was selected over all other vegetative matter. Comfrey is up to 33% protein, dry weight, and low in fiber, which makes it easily digestible. It is also high in vitamin B_{12} which it extracts from the soil and subsequently stores. Comfrey has been used for many human medicinal purposes and makes an excellent food for herbivorous fish. The Tilapia like it. It is a perennial and easy to grow in this climate. The drawback, as with most plants, is that it is 80% to 90% water and requires a good solar drying technique. (See the reference by Hills in the Bibliography.)

Azolla, a water fern, is also an excellent food for herbivorous fish as it is a symbiont with the blue-green alga *Anabaena,* which is capable of fixing atmospheric nitrogen. It, too, is high in protein content.

Live feeds, such as insects, worms and zooplankton, were also important and seemed to add to the vitality of the fish. Although midges were not used this season, they would have enhanced productivity. We are currently involved in the extensive development of live feed cultures.

A total of 27 kg (59.3 pounds at $12.00/50 pounds) of Purina Trout Chow was fed to the fish during the experiment which lasted until 26 October 1976, 126 days. The temperature profile of the main aquaculture pool for this period is illustrated on Graph 1. The experiment was extended this long to determine the potential growth of the fish. *Tilapia aurea* are believed to grow fastest in the first seventy days of their lives. The long trial was largely a social consideration because people in this culture generally prefer eating large fish. The protein content is just as high in smaller fish and the overall nutritive potential may be better, for, when fried hard, small Tilapia may be eaten whole. They are good and the small bones are not a problem. In places like Java, people are lucky to have a 2-3 cm long fish with their meals. The surplus feeding was also intended to help reduce the aggressive factor in order to select for fast growing individual Tilapia. The largest have been kept as breeders for next season. Such selection will only be possible if growth efficiency is a genetic variable in these fish.

The fish grew to 29 kg (63.8 pounds), an increase of 28.85 kg for 1,148 individuals. The wet fish to dry commercial feed conversion ratio was 1.1. In the past, the greatest productivity in the Miniature Ark was 25 kg (55 pounds) of fish. This was using polyculture techniques. This year's increase could be due to both the commercial feed input and the dense phytoplankton populations. Green algae is not nearly as easily assimilated by Tilapia as blue-green algae and bacteria because it is harder for the fish to break down the cellulose walls of the green algae through acid lysis in their stomachs. Moriarty (1973) found that *Tilapia nilotica,* also a phytoplankton feeder, was capable of assimilating 50% of the carbon from a species of *Chlorella,* another Chloroccacles, but up to 70% to 80% in *Anabaena* and *Microcystis,* blue-green algae. If a culture of the African blue-green algae *Spirulina platensis* could be grown compatibly in our system, it would be a superior food, for it is up to 68% protein and contains vitamins A, B_1, B_2, B_6, B_{12} and C. Culturing techniques are being developed in Japan (see the Nakamura reference). Some preliminary work in combination with our Tilapia research is being done at The Woods Hole Oceanographic Institution by Larry Brand. The *Spirulina* is also a good human food and is used as a flour supplement in parts of Africa. It is easily strained out of water and does not require high technologies of centrifugation for harvest. Like Tilapia, it requires a high pH and, so far as is known, a 0.1% salt solution is required, which would limit its use in terms of garden irrigation. There may be a strain, however, that would eliminate the necessity of the salt component. We do, as a rule, attempt to use indigenous species of phytoplankton which do not require sophisticated culturing techniques, but, if a simple technology could be found to allow the culturing of an alga like *Spirulina platensis* in our systems, it would be a tremendous advantage as both fish and human food.

The quality of the flavor of the fish from the Miniature Ark was the most disappointing factor. This year, for the first time, the fish from this system tasted slightly like stale fish pond algae, which is known as "off-flavor." The quality of the meat, however, was as good as ever. In trying to determine the reason for the "off-flavor", we noted two small areas on the bottom of the main fish culture pool which looked and smelled as if they had become anaerobic. Oxygen levels were lowest on the bottom, especially in the shaded southern portion. This situation did not develop in the Six Pack pool, which is a cement pond without any circulation, deeper than the Miniature Ark, having a thicker layer of sediments on the bottom. The production in the Six-Pack pond will be discussed in the following section. The "off-flavor" in one and not in the other may be explained by the species of fishes involved in the experiments. The chief difference in organisms between the Miniature Ark and the Six Pack was that, while the former contained a Tilapia monoculture, the latter housed a polyculture of both Tilapia and Israeli carp. The Mini-Ark was populated with juvenile Tilapia which did not engage in sexual behavior until late in the experiment, if at all, due to lack of sexual maturity. Unlike carp, Tilapia do not dig and stir up the bottom except during mating when, in courting behavior, the male Tilapia clears a spot on the bottom. The shallow sediment layer on the bottom of the Mini-Ark remained relatively undisturbed and, therefore, possibly became anaerobic. This could account for populations of anaerobic blue-green algae with geosmin isolated from some bacteria and blue-green algae. Geosmin has been found to be the compound causing "off-flavor" in an Actinomycetes, *Streptomyces,* by Yurkowski and Tabachek, and in a blue-green algae, *Symploca muscorum,* by Safferman *et al.* The "off-flavor" can be removed from the live fish by transferring them to fresh water for a few days. This is a common practice and has been done successfully with trout and catfish.

It would seem that the stirring of the bottom by the carp in the Six-Pack prevented a dense population of "off-tasting" organisms from becoming established. There were also adult Tilapia in the Six-Pack and their sexual behavior would increase the bottom stirring. We are considering using edible crayfish to aid further in stirring up the substrate, which would fill a niche using potential food sources from bottom detritus.

There may be another advantage to the inclusion of carp in a fish production system, as has been illustrated by Rabanal. In ponds in Alabama, where carp and goldfish were grown separately, he found lower ammonia concentrations in the carp pond. He believes that the stirring of the bottom by the carp caused more efficient absorption of ammonia by the clay colloids mixed in the water. There were higher nitrate concentrations in the carp ponds which he feels were due to the fact that the water was muddier and allowed in less light to drive the photosynthetic process which would have used up the nitrates. This resulted in less plant productivity.

These findings are important in optimizing our polyculture strategies. Our Miniature Ark research which focused on increasing productivity would have benefited from including other species, if for no other reason than to improve the taste of the fish.

The Six-Pack Pond and the Midge Pond

We conducted two studies last summer involving aquaculture in stagnant, unfiltered ponds. One pond was in the bioshelter, which was the prototype for the Ark which we call the Six-Pack, and the other was an unused pool in the midge production system. There are three basic physical differences between the ponds. The Six-Pack pond is made of cement, enclosed in a building, and square in shape measuring 4.1 meters on the sides and 1.7 meters in depth. It contains 29.25 cubic meters (7,725 gallons) of water. The midge pond has a plastic liner, is outdoors, and is a long narrow trench measuring 15.85 by 0.91 meters. It is 0.74 meters deep with a capacity of 10.7 cubic meters (2,820 gallons). The midge pond had a build-up of organic matter on the bottom and was open to invasion by many organisms from its surrounding environment. Both of these ponds received fish which had over-wintered in the house under crowded conditions. At the outset of the trials, both ponds were relatively sterile with respect to phytoplankton populations.

The Six-Pack

Fish were put in the Six-Pack pool at two different times. On 7 July 1976, 47 adult *Tilapia aurea* weighing 1,840 grams were introduced, and on 15 July, 40 more Tilapia weighing 3,820 grams were added, along with 6 mirror carp weighing 1,320 grams. The fish were fed 7.65 kg of Purina Trout Chow at about 100 grams per day plus cuttings and vegetable waste from the interior garden of the Six-Pack. The fish were harvested on 29 October 1976. At that time 60 Tilapia were found weighing 7,600 grams, an increase of 1,940 grams. Ten mirror carp were found weighing 5,350 grams, an increase of 4,030 grams. The total wet mass fish growth to mass of dry commercial feed ratio was 0.78 to 1. The relatively large growth of mirror carp in relation to that of the Tilapia is most likely due to their out-competing the Tilapia for the commercial feed. Observations during feeding confirmed the greater ability of the mirror carp to fend off the Tilapia. There was never a significant phytoplankton bloom which is a good Tilapia food source. This is due to the design of the building which allows little light to penetrate the pond. The northern half of the pool is covered by an opaque roof which eliminates some of the summer sunlight by shadowing part of the pool. The temperature profile of the pond during the experiment is described on Graph 1.

The Midge Pool

196 Tilapia weighing 5,520 grams (15.1 pounds) were put in the midge pool on 15 July 1976. Like those in the Six-Pack, these fish were at least one year old and had come from the over-wintered population. They were fed 6,840 grams of Purina Trout Chow. The pond was rich in other organisms, some edible and others not. These included frogs, tadpoles, a large painted turtle, zooplankton and a freshwater bryozoan colony. When the fish were put in, the water had a brownish hue and lacked a dense phytoplankton population. Within two weeks a dense phytoplankton population had developed. An adjacent pond without fish retained its brownish sterile appearance. Within a week the Tilapia had killed nearly all the tadpoles in the pond. Most were found floating with bite wounds on their bodies. Many of the tails had either been partially or completely bitten off.

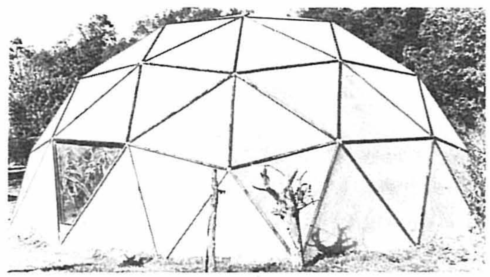
On October 6, 157 fish were harvested. They weighed 14.2 kg, which indicated a growth increase of 8.6 kg (19.1 pounds). The wet fish to dry commercial feed ratio was 1.27. In terms of the active feeding, this relatively high number was probably due to the other foods available in this pond and also to the consumption of insects which may have come to rest on its surface. The fish were extremely aggressive in their feeding behavior.

These fish were excellent in taste in spite of a rather thick sediment on the bottom. There are several probable reasons why a thick concentration of "off-flavoring" anaerobic organisms did not develop. The Tilapia were all adult and therefore active breeders involved in digging and turning over the bottom. The turtle's activity, depending on how long it was present, probably caused further stirring. The frogs also may have contributed to this. The shallowness of the pond would have provided for greater surface exchange with atmospheric oxygen both day and night in respect to volume of water. This would insure better respiration for the fish resulting in better metabolism. Dissolved oxygen levels were not measured.

The success of this simple shallow pond aquaculture is a hopeful indicator for Tilapia culture in rural areas or in any place where space is available. This kind of system is relatively easy to maintain. It could be used, for example, in crop rotation with rice in paddy culture, though the main drawback noted would be that pesticides are used to destroy rice parasites, like tadpole shrimp. Organic rice growing techniques have been undertaken at the Wehah Farm near Chico, California, by the Landsbergs. This is reported by Floyd Allen in *Organic Gardening and Farming Magazine.* They have begun using Gambusia, the mosquito fish, as a biological control for some of the parasites. Their rice harvest was only about one-half that usually produced by chemical methods. This was largely due to the condition of the soil and possibly could be remedied through such organic means as composting or the use of *Azolla**.

In the past the Chinese apparently worked out rice and fish culture strategies in conjunction with each other. The timing of planting and fish introduction have been worked on. I do not have detailed information as yet, but hopefully productive methods using organic, ecological techniques are being developed. We are beginning to look into these strategies.

* Azolla is an aquatic fern which lives in a symbiotic association with a blue-green algae (*Anabaena* sp.) capable of fixing atmospheric nitrogen which in turn is made available to rice as a nutrient source.



3 The Dome Pond

This year the aquaculture pond in the dome was used chiefly as a breeding pool for *Tilapia aurea.* Changes in the design and structure of the dome are described in the Bioshelter Section. They included the addition of a second thermal outer layer of Kalwall fiberglass, Sunlite premium grade. The internal elements remained relatively unchanged in terms of the $18.8m^3$ (4,960 gal.) pool and the filters. The fish cultured were mainly *Tilapia* with a few of the Chinese big head and silver carp. The carp were new to this system.

We had considerable success with *Tilapia* breeding in the pond. Between 3000 and 4000 young fish were produced. Originally 116 adult *Tilapia* were introduced. As the young were found and netted, they were placed in a small fine-meshed cage which was suspended in the pond.

The first *Tilapia* adults were put into the pond on 23 April 1976. The first young were spotted on 4 June 1976 – six weeks later. More adult *Tilapia* were added on 8 May 1976 (36 fish), 12 June 1976 (11 fish) and 23 June 1976 (14 fish). The total weight of these fish was 4,238 gms. Previously, on 9 December 1975, we had introduced 20 Chinese big head and silver carp at 40.8 gms. Again on 15 July 1976, we added 14 additional Chinese carp at 36 gms. We had two species of Chinese carp and at the time of acquisition we were not able to discern the difference because they had arrived in a mixed lot and they were so small. The total mass of fish put into the system was 4,314.8 gms.

The main feed used in the dome was vegetative matter with some additional commercial feed. The fish were given an excess of edible plants each day. The inedible parts that were too hard for them to eat were removed to reduce the build-up of organic matter in the pond. The feed consisted of a seasonal mixture of vetch, comfrey, marigold flowers, soy flour, *Hydrodictyon,* and *Azolla* and, in addition, some zooplankton, crushed snails and Purina Trout Chow. The only quantitative measure made was of the trout chow which amounted to 10.03 kg (23.8 lbs). The pond had a rich phytoplankton population measuring 40 cm or less with a Secchi disc. Both the *Tilapia* and the Chinese carp are capable of feeding upon this phytoplankton.

The carp can live at much cooler temperatures than the *Tilapia* – 4°C as opposed to 12°C, but there are at least three drawbacks to using them. They do not breed in our system and must be induced to do so artificially. They are quite fragile fish and require careful handling. In addition, they did not grow very well, as the following data will indicate. This growth problem could be attributed to their being out-competed for food by the *Tilapia* or to their inability to assimilate well indigenous species of phytoplankton or other available feeds.

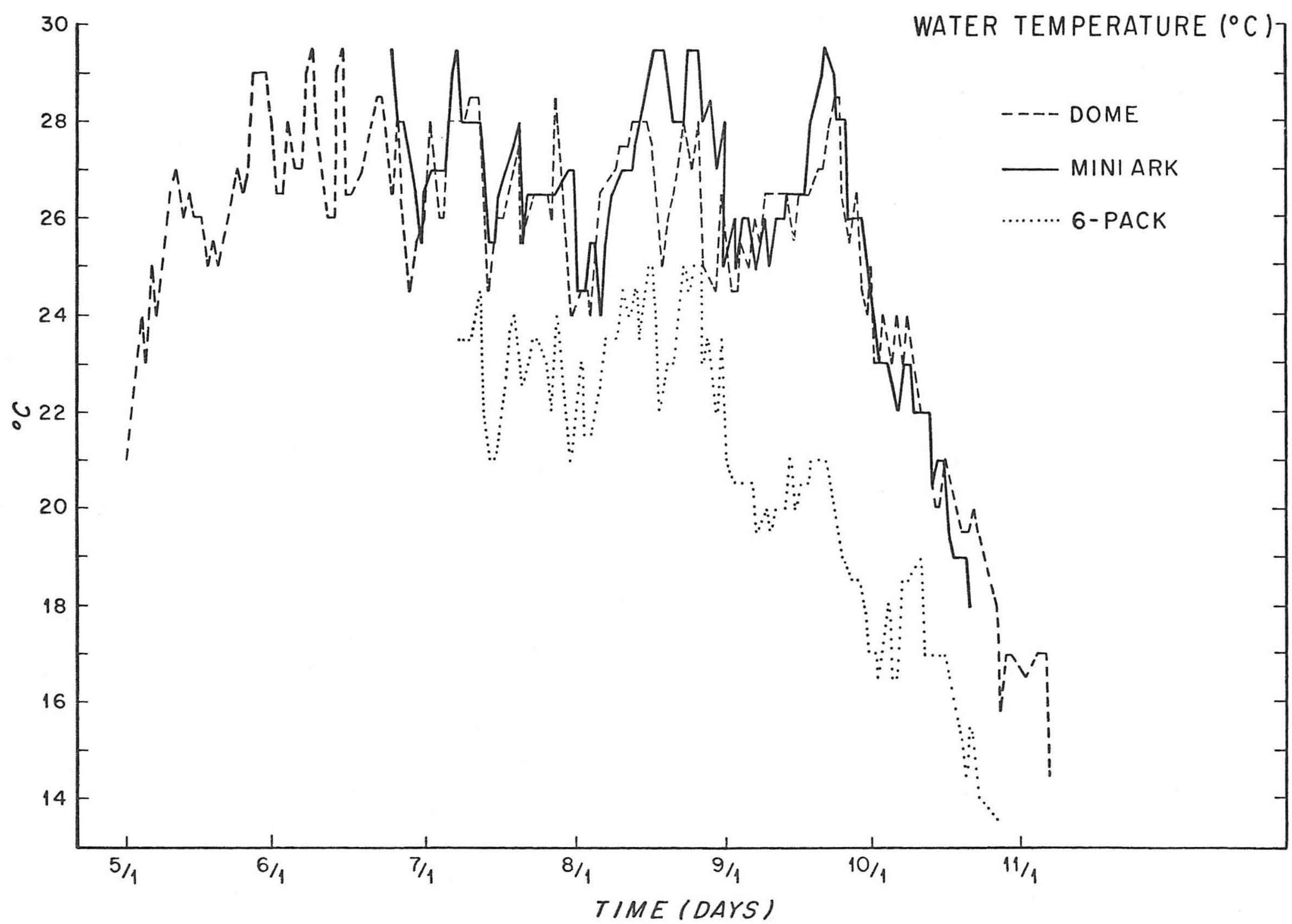
The total mass of fish removed from the dome pond

Photo by Hilde Maingay

was 27.7 kg (60.94 lbs). There were 127 large, fillet size *Tilapia* at 26 kg (57.2 lbs) or 206.3 gm per fish, 180 small *Tilapia* at 1 kg (2.2 lbs) and fifteen Chinese carp at 675 gms (1.5 lbs). The net increase in weight was 23.4 kg (51.4 lbs) which gives a wet fish to dry commercial feed ratio of 2.2. This high number is due to their primarily feeding on a large mass of unweighed vegetative matter and phytoplankton not included in the food input to production estimate.

The fish from the dome had an excellent flavor and the pond bottom was free of any questionable smell. Although this experiment was like the one conducted in the Mini Ark in that it was chiefly a mono-culture, a possible anaerobic condition did not prevail for at least two reasons. The first was that the bottom of the dome pond is covered with a couple of centimeters of easily stirred sand put there to protect the plastic liner from being punctured when the pool is drained during harvesting. Although *Tilapia* generally do not dig and stir bottom material, sexually mature fish were included initially and the males do dig holes in the bottom substrate as part of their courtship activities. *Tilapia* procreate at temperatures between 26°C and 35°C. (The daily pool temperature profile for the production period is plotted in graph 1.) They require between five to seven weeks between matings, but it is not necessarily a seasonal event and, therefore, with a sufficiently large male population, the digging behavior and stirring of the bottom is probably continuous. A second reason for the absence of smell could be that the dissolved oxygen concentrations in the dome pond were generally higher than those in the Mini Ark, so chances of an anaerobic condition developing were much reduced.

The dome aquaculture system had its highest productivity to date this season, providing an abundant new population of *Tilapia aurea*. As in our other experiments, we are working toward the elimination of the commercial feed component. A description of some of the physical and chemical parameters being tried can be found in the Bioshelter Section of this *Journal*.



GRAPH 1. MAXIMUM DAILY WATER TEMPERATURES RECORDED DURING EXPERIMENTATION IN NOTED AQUACULTURE SYSTEMS

SUMMARY OF THE WORK WITH SEMI-CLOSED AQUATIC SYSTEMS

The past year's work with semi-closed aquatic systems demonstrated a significant step toward understanding their biological complexity and production potential. The five systems tested showed how the various semi-closed system strategies compare in terms of energy requirements and their effects on fish growth. The findings provide important guidelines for future work in aquaculture research.

TABLE I.

System	1 Total Volume (m^3)	2 Surface Area (m^2)	3 Fish Production (kg)	4 Dry Feed (kg)	5 Conversion Ratio West Fish/ Dry Feed	6 Time (Days)
Miniature Ark: Re-Circulating "River" Enclosed by Three Small Greenhouses	34.5	34.1	28.85	26.95	1.08	126
Dome Pond: Biological Filtration and Re-Circulation	18.8	18.7	23.36	10.83	2.20	201
Six-Pack: Still	29.24	16.9	5.97	7.65	0.78	114
Midge Pond: Outdoors	10.7	14.5	8.65	6.84	1.27	106
Solar Pond No. 1 (Winter)	2.78	1.82	0.845	2.9	0.29	132
Solar Pond No. 1 (Summer)	2.78	1.82	3.55	6.7	0.53	179
Solar Pond No. 2 First Half Summer	2.78	1.82	6.98	6.95	1.00	98
Solar Pond No. 2 Second Half Summer	2.78	1.82	3.44	3.83	0.90	108

Aquaculture Table I lists the physical dimensions of each system and the data with respect to fish production, feed growth ratios and time required for growth. A discussion of each of these systems can be found in the preceding articles. Table II provides comparisons between the systems in terms of volume, time and surface area. The data for Solar Pond No. 2 illustrate the viability of this kind of intensive aquaculture for protein production. It should be remembered that these are the results of our first trials. Additional experiments should increase production. The results indicate the significance of light on herbivorous fish production. The increased population of phytoplankton resulting provides high oxygenation and algae production through heightened photosynthesis. The high concentrations of dissolved oxygen accelerate the metabolism of the fish, especially in warm water species, and the increased phytoplankton productivity provides more feed for mature Tilapia.

The open trench system in the midge works had significantly lower fish production than the solar ponds. It required the least energy input, however, as it was neither aerated nor used pumps for water circulation as was the case with the Six Pack Pond. The open trench was the shallowest of the sub-surface systems allowing both for the greatest gas exchange with the atmosphere and phytoplankton photosynthesis per unit volume of total water mass.

TABLE II.

System	1 Mass Production per m^2 (kg)	2 Mass (kg) Production per m^2 per 100 Days	3 Mass (kg) Production per m^2 per Year	4 Mass (kg) Production per Hectare	5 Mass (kg) Production Per Hectare per 100 Days	6 Mass (kg) Production per Hectare per Year	7 Mass Production per m^3 (kg)	8 Mass (kg) Production per m^3 per 100 Days	9 Mass (kg) Production per m^3 per Year
Miniature Ark: Re-Circulating "River" Enclosed by Three Small Greenhouses	0.85	0.67	2.45	8,460.4	6,714.6	24,508.3	0.84	0.67	2.45
Dome Pond: Biological Filtration and Re-Circulation	1.25	0.62	2.26	12,492.	6,214.9	22,684.4	1.24	0.62	2.26
Six-Pack: Still	0.35	0.31	1.13	3,532.5	3,098.7	11,310.3	0.26	0.23	0.84
Midge Pond: Outdoors	0.60	0.57	2.08	5,969.	5,631.1	20,553.5	0.81	0.76	2.77
Solar Pond No. 1 (Winter)	0.46	0.35	1.28	4,641.	3,515.9	12,833.0	1.04	0.79	2.88
Solar Pond No. 1 (Summer)	1.95	1.09	3.98	19,505.	10,896.6	39,772.6	1.27	0.71	2.59
Solar Pond No. 2 First Half Summer	3.84	3.92	14.31	38,351.6	39,134.3	142,840.2	2.50	2.55	9.31
Solar Pond No. 2 Second Half Summer	1.89	1.75	6.39	18,925.8	17,523.8	63,961.9	1.38	1.28	4.67

It was the simplest in construction and function and it produced a significant amount of fish — one and a third times greater than comparable surface areas of South China herbivore production.

A comparison of the sub-surface and Solar Algae ponds illustrates the significance of light upon the productivity of aquatic systems using herbivores as consumers. The understanding of the interrelationship and utilization of light by algae is the most important finding from the year's research. The use of solar energy to heat, oxygenate and purify pond water using phytoplankton which, in addition, serve as feed for the Tilapia is extremely useful in fish culture. The uses of light will be a strong consideration in our continuing aquatic system design strategies and maintenance procedures.

Cage Culture

– William O. McLarney

New Alchemy's newest aquaculture project is the rearing of fish in floating cages. The cages were placed in Grassy Pond, which borders on the New Alchemy farm. I had hoped to be able to write a glowing "success story" about our first experience in cage culture but it didn't work out that way, for reasons understood and otherwise. Instead of a success story with how-to-do-it instructions, this is a progress report essay on the art of cage culture and a commentary on the state of fish farming in North America.

Let me hasten to state that I have not lost faith in the concept of cage culture. Growing fish in floating cages is a more or less traditional technique in Cambodia, Java and other parts of Southeast Asia. More recently, it has been applied successfully in large scale commercial fish culture in Japan and the United States. More to the point is the recent success in small scale cage culture of bluegills *(Lepomis macrochirus)* and hybrid sunfishes in the Midwest where fish farmers have been able to raise up to 100 pounds of sunfish in 3'x3'x3' cages in a single growing season. (Ligler, 1971)

I think the potential of this form of fish culture as a family or small-scale commercial food source is obvious. The implication of successful fish culture in small cages is that anyone with access to unpolluted standing water could raise fish for the table and perhaps for sale. Not everyone has such access, but a lot of people do. In Massachusetts alone, for example, there are 151,739 acres of ponds and lakes. To apply the idea to a part of the country not so favored with natural lakes and ponds, there are 75,000 artificial "farm ponds" in the state of Illinois alone, which amounts to at least 50,000 acres of potentially productive water.

I have been asked how our cage culture work relates to the Back Yard Fish Farm and similar semi-closed fish culture systems for which New Alchemy has previously been known. (McLarney and Todd, 1974) Both are intended to produce fish at low cost in a small space and in quantities appropriate for homestead use. In both methods, the fish are confined in a very small space, which simplifies feeding, inspection, and harvesting. Those without access to a natural body of water or a site suitable for building an outdoor pond will have to resort to something on the order of our Back Yard Fish Farm in order to raise fish. But for those who do own a pond, or have access to one, or can build one, there are at least two advantages to cage culture:

1. The confinement of fish in a small volume of water, as in the Back Yard Fish Farm, necessitates recirculation and filtration of the water if substantial amounts of fish are to be grown. In a large outdoor body of water, these needs are eliminated, but the particular advantages of keeping the fish in a small enclosure are lost. Cage culture combines the best of both approaches by confining the fish in a small *space*, but not a small *volume* of water. That is, the water in the cage is continually being replaced by clean water from the surrounding pond. In fact, the fish through their normal breathing and swimming movements act as a "pump" to circulate their own water.

2. In many cases, fish which already inhabit the pond can be placed in the cages for intensive culture. In this way, ponds which are overpopulated or otherwise poorly suited for food fish culture can be used as natural "hatcheries", eliminating the expense and labor of purchasing or breeding stock.

Cage culture has the further advantage of being one of the few methods of fish culture which is compatible with the other values and uses of a pond. A pond like Grassy Pond, with its extensive shallows, brush and "weeds", irregular shoreline, natural fish predators, etc., viewed solely from a food fish production standpoint, is very "inefficient." But to convert it to a conventional, "efficient" fish culture pond would seriously compromise or destroy its value in terms of sport fishing and other recreational use, wildlife habitat, and esthetic pleasure. To use it for cage culture, on the other hand, modifies only a few square feet of the pond's surface. The cages may even enhance fishing; we find that bullheads, in particular, tend to congregate under the cages, fattening on morsels of food which slip by the caged fish.

We are by no means the first ones to perceive these advantages. The editors of Farm Pond Harvest magazine, in particular, have been active in promoting the use of cage culture and other methods to restore the American farm pond to its intended role as a food-producing resource (see addresses at end of article). However, their work, like that of most others in the field, has been heavily dependent on the use of commercial fish feeds. For those of you who have not been exposed to conventional American fish culture, I should point out that it is moving rapidly in the "agribusiness" direction. One of the clearest symptoms of this is the composition of commercial fish feeds. There are numerous manufacturers of dry feeds for trout and catfish, our two principal aquaculture crops. The first ten ingredients listed on the label of one brand of trout feed are: "fish meal, meat meal, soya bean meal, wheat germ meal, fish fiber and glandular meal, animal liver meal, corn gluten meal, dehydrated alfalfa meal, dried skim milk, dried whey products..... " The list goes on and concludes with no less than 13 synthetic vitamins and 6 added minerals.

Scientifically inclined readers may be appalled at the energetics of formulating such a feed. Others will question the appropriateness of feeding fish on potentially useful human food. Still others will criticize the ethics or politics of using inexpensive fish from the coasts of South America to make expensive fish for the North American table. The least debatable drawback to such prepared feeds is the expense. Each of the ingredients costs, and these costs are rising. I know of one case where a fish farm, with the help of an economist, formulated its own low cost, high growth feed for a particular species of fish; the cost of this feed has increased by a factor of 6 in as many years. It is hard to grow fish inexpensively with an expensive food.

The prepared feeds are effective; at the present time we cannot say "Feed this and that and your fish will grow as well or better than they will on a prepared commercial feed." This is because, given the nature of American business and agriculture, virtually all the research that has been done on fish nutrition has aimed toward the development of "complete" prepared diets. It is assumed, not proven, that natural or fresh foods cannot compete economically.

I therefore conceived that it would be useful to grow fish in cages in Grassy Pond, feeding some on prepared diets at conventional rates and others on "natural" foods we could provide at very low cost and without competing with our own diets. For reasons which we do not fully understand, we failed to produce significant quantities of edible size fish on either diet. However, I think the work sheds some light on both the relative value of both types of diet and on the problems and techniques of cage culture. It is therefore reported here.

We began with only 3 cages, due to a lack of funding for the project. The mesh material for the cages was Vexar, a nylon made by DuPont specifically for use in fish cages. Fish cages have also been made of plastic coated wire, but fish farmers report this has not been as reliable as Vexar. Imagine the disappointment of the fish farmer who pulls up his year's crop — and watches it fall through the bottom of the cage. It has happened. The past winter, in Colombia, I observed some beautiful and durable cages made from strips of guadua, a type of bamboo, but I know of no indigenous North American material with similar qualities. Whatever type of cage material you choose, to maximize water circulation and minimize the need for cleaning, use the largest mesh size that will contain the fish. Ours was one quarter inch.

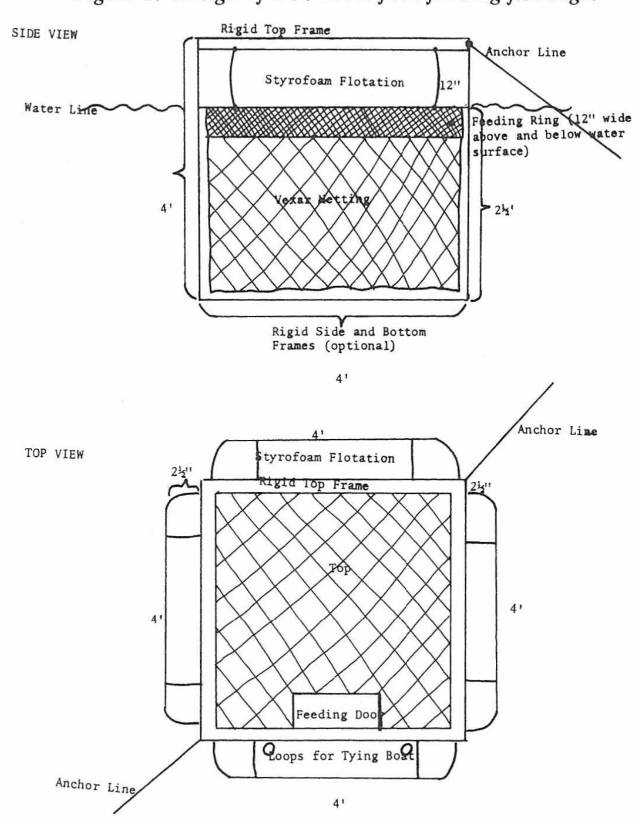
Our cages were provided with a rigid wooden frame at the surface, but were otherwise unsupported. They were constructed by sewing together sections of Vexar netting with nylon line. Commercially manufactured cages have a rigid frame on all sides, and we found out why. The unsupported cage walls tended to buckle slightly, not enough to deform seriously the cages, but enough to begin forming cracks in the Vexar. In one cage, these cracks eventually opened, forming holes large enough to permit the escape of fish.

Flotation for the cages was provided by 4 pieces of styrofoam 36" x 9" x 1", attached near the top so that 1 foot of the total cage height of 4 feet was above the surface. We felt this eliminated the necessity for tops on the cages, though if one were growing a species of fish more given to jumping than sunfish, tops would be necessary. The floats were enclosed in canvas bags so that the styrofoam, should it break, would not float away.

The cages were anchored in the pond by means of cinder blocks attached to two of the corners with nylon line. They were set in water deep enough that the bottoms of the cages were clear of the pond bottom at all times.

Figure 1 is a sketch of one of our cages, with a wooden frame added on all sides. Another feature we want to add next time is some sort of snap arrangement, so that a boat can be quickly and snugly fastened to the side of the cage.

Figure 1. Design of a 64 cubic foot floating fish cage.



For those who do not want to go to the bother of building their own cages, I have appended the addresses of a number of commercial cage manufacturers. One of them, Inqua Corporation, also offers a $1 booklet entitled "Profitable Cage Culture", (Neff & Barrett, 1975) which goes into the why and how of growing fish in floating cages in much greater detail than I can here.

Each cage was stocked with 200 "hybrid bluegills", a cross between male green sunfish, *Lepomis cyanellus* and female bluegills. The use of these fish is not essential to cage culture, which can be applied to most species which can be cultured at all. I chose the hybrid because it is supposedly a particularly fast growing fish which combines all the desirable characteristics of the bluegill with a mouth nearly as large as that of the green sunfish, so that it is easier to feed.

Each of the 3 cages was stocked on May 14 with approximately 200 young fish weighing a little over 2 grams each. The cages were designated A, B and C. For the first 15 weeks of the experiment, the fish in Cage A received only natural foods, while those in Cage B were fed daily except Sundays with 1/8 inch Silver Cup floating trout feed in an amount equivalent to 2% of the estimated total weight of fish in the cage. To form an idea as to the importance of foods which entered the cages naturally, the fish in Cage C were not fed during this time.

There were three principal components of the natural food diet:

1. Earthworms: This is of course the archetypal fish bait, and for good reason. Fish, including our sunfish, love them. Earthworms have another advantage for the fish farmer in that good methods have been developed for raising them (see Book Review — page 29) though fish farmers have not taken advantage of this. We started a small earthworm culture this year, but the bulk of our worms were gathered from compost or leaves. Worms were fed to the fish by placing them on a perforated styrofoam float. They were eaten one by one as they worked down through the holes.

2. Flying insects: These were captured with the aid of ultraviolet "bug lights." We had an old style bug light with an electric killing grid, which was donated several years ago by Gilbert Electronics of Jonesboro, Arkansas, and this was used. But this year we received the generous donation of two "Will-O'-the Wisp" bug lights from Hedlunds of Medford, Wisconsin (see list of addresses). These lights are manufactured expressly for use in fish culture. The insects are attracted to the light, sucked in by an impeller fan and blown down into the water. Due to a lack of electrical wire, we were unable to install ours over the cages, but instead had to attach a bag to collect the insects. Certainly the trap's effectiveness was reduced, but on good nights we harvested as much as a quarter pound of insects, mainly midges and moths. On bad nights the harvest was virtually nil, even during June, our peak "bug season." I imagine these lights would be more effective consistently in the Midwest or South where hot, sultry summer nights prevail, rather than on Cape Cod where windy nights are the rule. Nevertheless, the cost of providing high quality fish food in this manner was less than a nickel a day using conventional electric power. Were we to succeed in developing a U-V bug light powered by a wind-charged battery, that would be as close to a free nocturnal lunch for fish as one could get.

3. Midge larvae: Cage C was provided with a 2' x 6' burlap sheet of these larvae every other day; their culture is described in previous issues of *The Journal of the New Alchemists* (McLarney, 1974; McLarney, Levine and Sherman, 1976).

Occasional tidbits of other live or fresh foods were added, but not in significant amounts. It was more difficult to quantify accurately the natural foods than the dry feed. The amount of insects caught by the lights, in particular, was out of our control. The quantity of midges fed also varied from feeding to feeding; assuming our production rates are essentially the same as in previous years, the average feeding amounted to about 100 grams. The quantity of worms fed was more amenable to regulation, being a function of the amount of labor expended. However, since the primary goal was to develop a feeding system which would be practical for a homesteader or small farmer, the total amount of natural foods used was limited to what could be gathered in an hour. Thus, on some days, particularly later in the season, the combined dry weight of the three types of natural food fell short of the total weight of dry food fed. The approximate proportions (dry weight) of worms, flying insects and midge larvae in the natural foods diet were 75%, 20% and 5% respectively.

About every two weeks a sample of 30 fish was taken from each cage and weighed. This figure was used to estimate the total weight of fish in the cage, which was in turn used in preparing new feeding rates. Comparison with the actual weight of all the fish in a cage, on the three instances when such a comparison was made, showed that our estimates ran about 10% low.

The feeding and sampling regimes just described were followed throughout the study, with the following changes:

1. On June 29 it was determined that the fish in Cage C had ceased growing altogether, and perhaps had started to lose weight. The mean weight of the sample fish on that date was 2.2 grams; on June 14 it had been 3.3 grams. From June 30 through September 1, they received the same dry feed as the fish in Cage B, but in daily amounts equivalent to *3%* of the total weight of fish in the cage.

2. As the daily feed rations became larger, it became less certain that all the food was being consumed. On

August 4 we therefore began feeding twice a day.

3. Sometime between August 31 and September 11 a hole was formed in Cage B, permitting the escape of about 75% of the fish. When this was discovered, the remainder of the fish were removed, weighed and redistributed between Cages A and C. From then on the experiment was altered as follows: Cage C was fed with dry food at the 2% rate, Cage A received the same *plus* 100 worms (approximately 60 grams dry weight) and an average of 2.5 grams (dry weight) of flying insects daily.

4. Our first killing frost occurred on October 12; this coincided with a drastic drop in the water temperature. This was reflected in a marked reduction in feeding by the fish. It was thus decided to make the final harvest on October 19.

We had aimed at producing ¼ lb. (114 gram) fish by the end of October. Assuming 100% survival and no escape of fish, this would have given us 600 sunfish weighing a total of 150 lbs. (68,100 grams). Our actual final harvest was 367 fish weighing 14.4 lbs. (6,525 grams) or 9.6% of our goal. The mean weight of these fish was 0.04 lb. (17.8 grams) or 16% of the target weight. From a production point of view, a failure; but there is something to be learned from the experience and it has not caused me to lose faith in the potential of cage culture as a means of producing food fish on Cape Cod or elsewhere.

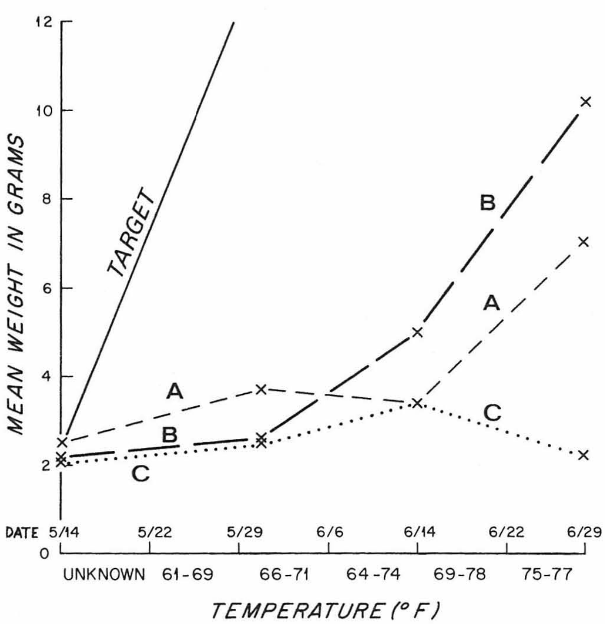


Table 1. Growth of Caged Hybrid Sunfish, May 14-June 29

Cage	Initial total wt. of fish (May 14)	Initial mean wt. of fish	Est. total wt. of fish (June 29)	Mean wt. of sample fish (June 29)	Per cent growth (based on mean wts.)
A	513 grams	2.5 grams	1420 grams	7.1 grams	184%
B	457 "	2.2 "	2040 "	10.2 "	325%
C	440 "	2.1 "	480 "	2.4 "	14%
Total	1410 "	2.3 "	3940 "	6.6 "	187%

In an attempt to analyze where we went wrong and to illustrate what we have perhaps learned, let me offer a series of graphs and tables illustrating the estimated total and mean weights of fish in Cages A, B and C, and their rate of growth during 3 portions of the study period.

Graph/Table 1 covers the period from stocking (May 14) through June 29; feeding commenced May 18. The first thing one notices from the graph is that we got off to a bad start. While in the latter part of the period (June 14 to 29) growth was satisfactory, it was certainly not so prior to that time. It may be that both the 1/8" pellets and the natural foods were too large for the fish, and that they were forced to derive a significant part of their nutrition from plankton entering the cages naturally. That this is possible is shown by the curve for Cage C, where the fish realized some growth during the period May 14 to June 14, although they were not fed.

Graph/Table 2 covers the period June 30 to September 11, during which time all three cages were being fed. Although the fish in Cage C were receiving 3% of their estimated body weight in dry food, while those in Cage B received only 2%, there is no apparent difference in growth rate except during the first two weeks of the period, which was the first time Cage C was fed at all.

The abrupt decline in mean weight of Cage B fish in the last two weeks of the period is apparently connected to the escape of 157 fish of a total of 208 during that time. Had individual fish actually lost weight at the rate indicated by the curve, it would certainly have manifested itself in poor physical condition of the fish, which was not noted during the September 11 harvest. For the sake of facilitating comparison, data from the August 31 sampling rather than the September 11 one are presented in Table 2.

Graph/Table 3 covers the final 6 weeks of the study, during which time both cages received dry feed, while Cage A also received a natural foods supplement. Growth, while very poor in both cages, was somewhat better in Cage A. The loss of weight in the last 2 weeks is associated with a sharp decline in water temperature during that time. During October most of the fish refused to accept dry feed, although natural foods were accepted whenever they were offered.

The superior growth rates of the fish which received dry feed may reflect not so much any superiority of that diet, but the difficulty of providing an adequate amount of natural food. It is virtually inconceivable that a diet composed of live earthworms and a great variety of fresh insects could be deficient in proteins or vitamins, but it may have fallen short of the fishes' carbohydrate needs. We could, of course, increase the total weight of natural foods and therefore the amount of carbohy-

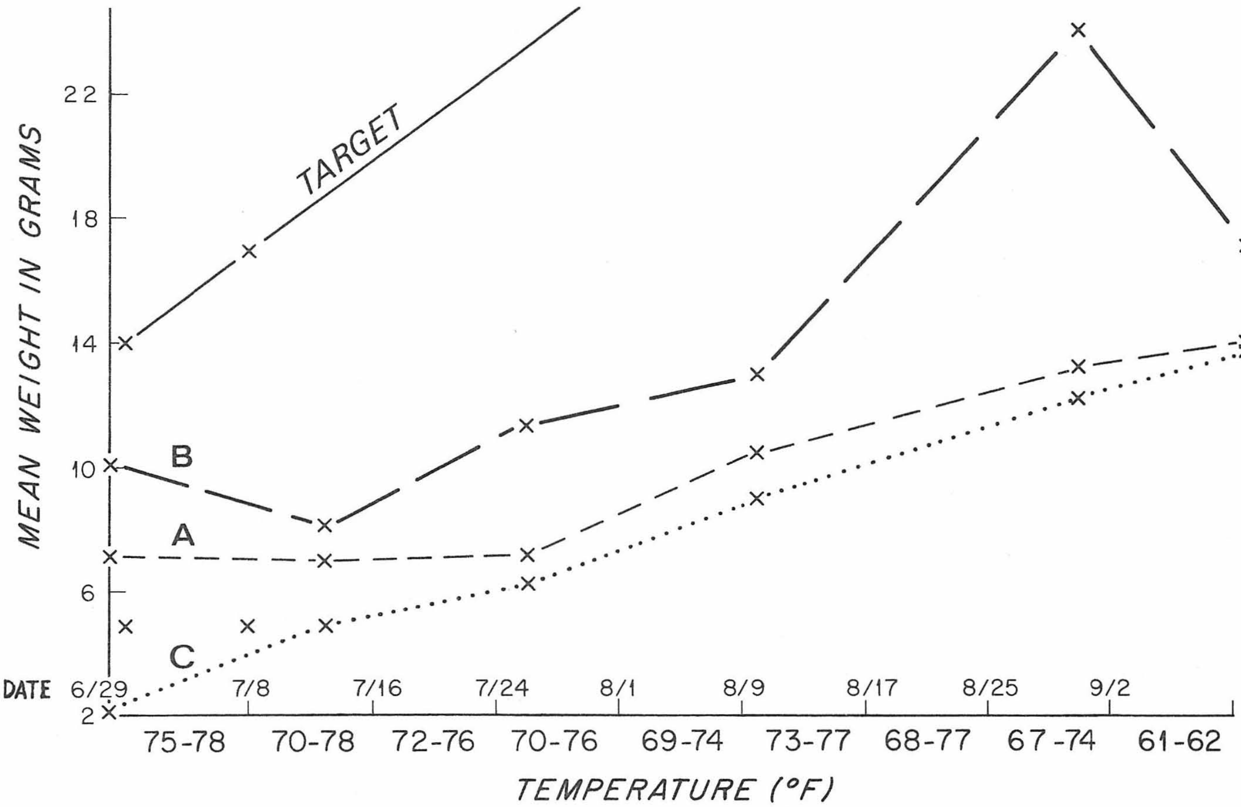


Table 2. Growth of Caged Hybrid Sunfish, June 30-August 31

Cage	Est. total wt. of fish (June 29)	Mean wt. of sample fish (June 29)	Est. total wt. of fish (Aug. 31)	Mean wt. of sample fish (Aug. 31)	Per cent growth (June 30-Aug. 31-based on mean wts.)	Per cent growth (May 14-Aug. 31 - based on mean wts.)
A	1420 grams	7.1 grams	2640 grams	13.2 grams	86%	428%
B	2040 "	10.2 "	4820 "	24.1 "	136%	995%
C	440 "	2.4 "	2460 "	12.3 "	413%	957%
Total	3940 "	6.6 "	9920 "	16.5 "	151%	617%

drates reaching the fish by improving the efficiency of our worm culture or by adding additional types of food. But we should also consider a compromise feeding strategy. Carbohydrate is relatively easy and inexpensive to supply in dry form; the cost of prepared fish feeds is largely due to the protein components. On the other hand, protein and vitamins are present in high proportions in most natural foods. It may be that the "ideal" fish diet would be a dry feed made of cheap grains, plus a smaller quantity of live or fresh food of animal origin.

Comparison of the different diets aside, the harvests from the cages were uniformly disappointing. One factor which may have contributed to this has already been mentioned — use of food particles too large for the small fish in the first month of the study.

There may also have been some problems with water quality. Periodic testing of dis-

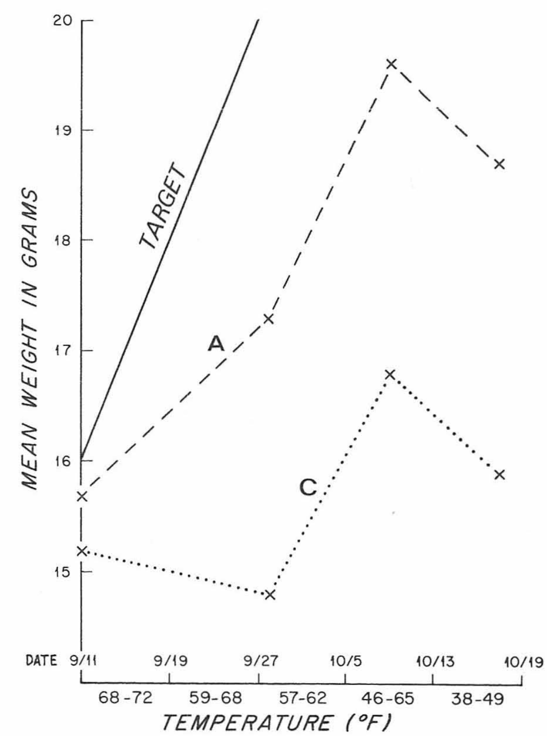


Table 3. Growth of Caged Hybrid Sunfish, September 12-October 19

Cage	Est. total wt. of fish (Sept. 12)	Mean wt. of sample fish (Sept. 12)	Total wt. of fish (Oct. 19)	Mean wt. of fish, (Oct. 19)	Per cent growth Sept. 12-(Oct.19 - based on mean wts.)	Per cent growth May 14-(Oct.19 - based on mean wts.)
A	3535 grams	15.7 grams	4020 grams	18.7 grams	19%	———
C	3430 "	15.2 "	2505 "	15.9 "	5%	———
Total	6965 "	15.3 "	6525 "	17.8 "	16%	674

solved oxygen concentration and pH in the cages and in the open pond always revealed near-optimum levels. No differences were observed between the two environments. But there may have been other problems we were unequipped to detect. Due to unusual hydrological conditions which prevailed in 1976, the volume of water in Grassy Pond was well below normal and the channel which ordinarily connects it with a larger pond dried up. This combination of circumstances may have contributed to a build-up of sulfur compounds or other harmful substances which would normally have been flushed out or diluted. (The presence of sulfur was obvious to anyone wading in the pond.)

Time of feeding may have been more important than we at first surmised. Initially the fish were fed only in the morning; later a late afternoon feeding was added to the schedule. Feeding during the full heat of the day was avoided, but a strict schedule was not kept. At first, the fish fed enthusiastically whenever food was offered; but, as the season progressed, they became more reluctant to accept the dry feed. Late in the season a few feedings were done very near dawn or dusk, and the fish appeared much more enthusiastic. It seems as though better food utilization might have occurred if we maintained a strict dawn/dusk feeding routine.

Of course, the total weight of fish obtained in the final harvest was reduced by the loss of some individuals. I have mentioned the loss of the majority of the fish from Cage B. At various times during the year, 15 fish were lost due to diseases or accidents. At the final harvest, 16 other fish were missing from Cage A and 68 from Cage C. It seems unlikely that these fish could have escaped, but neither is there any other apparent explanation for their disappearance.

There is another possible reason for the low production of our cages which should be considered. I may have chosen the wrong fish. Hybrid sunfish are a new idea in aquaculture, and a good one; but in my excitement over them I neglected to consider carefully the character of the environment I chose to work in. At least 12 species of fish inhabit Grassy Pond. Among them are two sunfishes, the bluegill, one of the parent species of our hybrids and the pumpkinseed *(Lepomis gibbosus)*. Neither grows rapidly nor attains large size frequently in Grassy Pond, although both species do well in nearby ponds. The brown bullhead *(Ictalurus nebulosus)*, on the other hand, does better in Grassy Pond than in most ponds in our vicinity. The brown bullhead is a fine food fish with omnivorous feeding habits and generally hardy; it should do well in cage culture. In 1977, funds permitting, we shall test both sunfish and bullheads with a variety of diets incorporating both prepared dry feeds and fresh natural foods.

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ADDRESSES OF SUPPLIERS OF EQUIPMENT AND INFORMATION CITED:

Farm Pond Harvest. Professional Sportsman's Publishing Company, Box AA, Dept. C , Momence, Illinois 60954.

Manufacturers of cages and materials for making cages:

Astra Pharmaceutical Products, Inc., Framingham, Massachusetts 01701. (Cages)

E. I. DuPont de Nemours and Co., Inc., Film Department, Wilmington, Delaware 19898. (Vexar netting)

Inqua Corporation, P. O. Box 1325, Homestead, Florida 33030. (Cages)

Panduit Corporation, 17303 South Ridgeland Avenue, Tinley Park, Illinois 60477. (Ties for fastening netting to cage frames)

C. E. Shepherd Company, P. O. Box 9445, Houston, Texas 77011. (Cages and coated wire for making cages)

Manufacturers of "bug lights"

Environmental Systems, Inc., RFD 1, Peterborough, New Hampshire 03458.

Gilbert Electronics, Inc., 3113 East Nettleton Avenue, Jonesboro, Arkansas 72401.

Hedlunds of Medford, Inc., P. O. Box 305, Medford, Wisconsin 54451.

Ken's Channel Catfish - Hybrid Bream Hatchery and Fish Farm. Route 1, Alapaha, Georgia 31622.