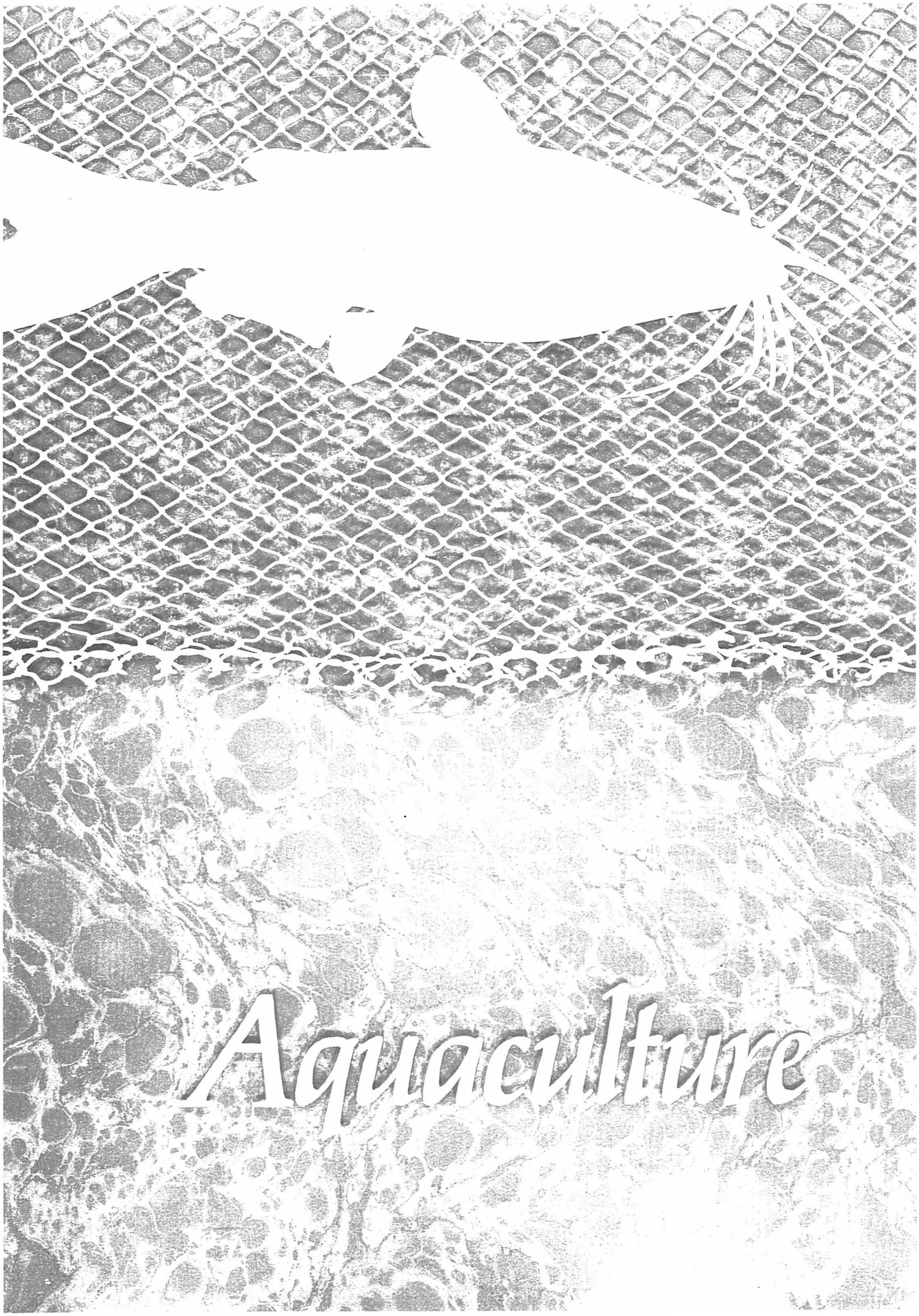


Aquaculture

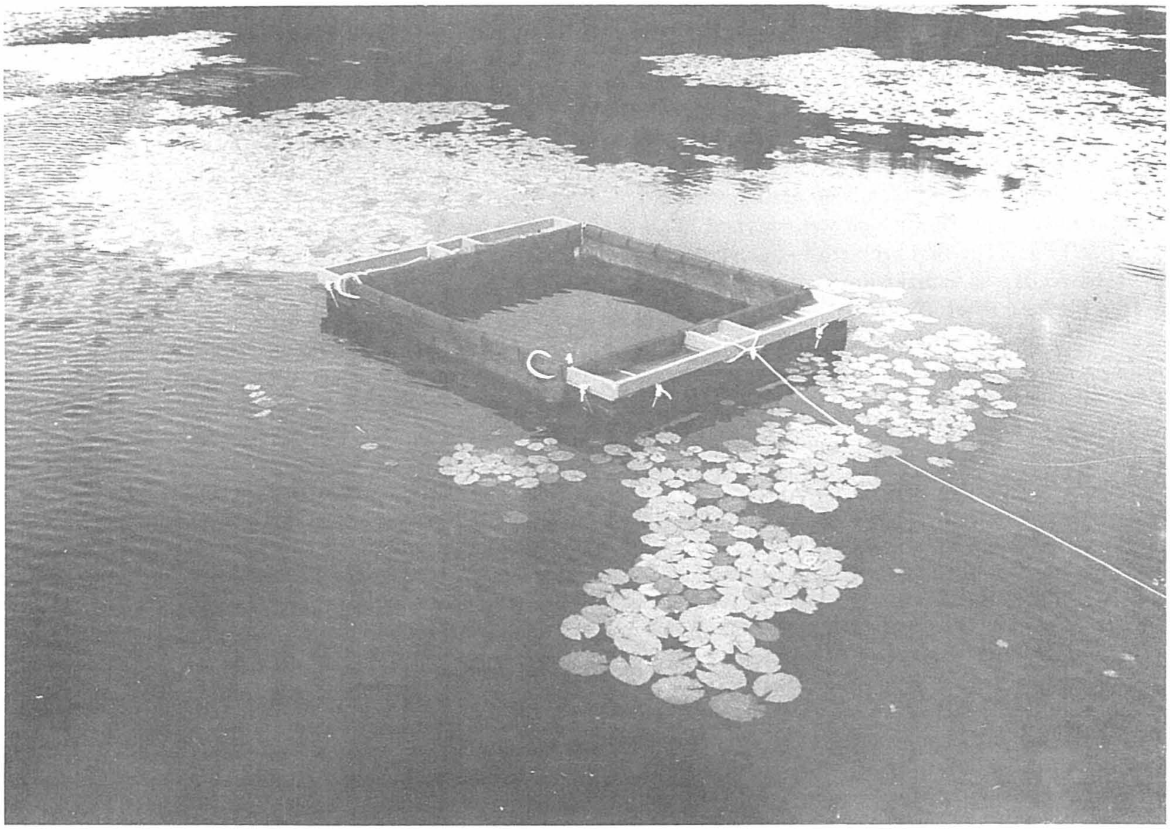
As was the case with our work with the bioshelters, the past year's aquaculture research was marked less by breakthroughs and landmark achievements than the last and more by efforts to understand more thoroughly the systems that we already have. Ron Zweig is in charge of our research in semi-closed system aquaculture. He was also the first one of us to use a computer to monitor a system, work that he has continued to do. During the summer of 1977, however, his collection of data no longer entailed the mile-long computer read-outs from the chart recorder that had been used to record phenomena in the Dome the previous year. Some of us — the terrible joke wing — were rather sorry as we had developed an appealing collective image of Ron, his charts extending to the horizon something like the running fence, pedalling a bicycle along beside them in order to read his data, whizzing simultaneously through space and time and, occasionally, when sighting a particularly unusual blip, reversing and jolting backward for a day or so to re-examine, say, July 17th.

For the summer of 1977, his means of monitoring were more subtle, using a microcomputer instead of a chart recorder. His observations of the life cycle in a solar-algae pond are recorded in "The Birth and Maturity of an Aquatic Ecosystem." His article entitled "Investigations of Semi-Closed Aquatic Ecosystems" is a report on his continuing experiments on just that. He discusses various systems, feeds and culture techniques and contrasts the advantages and disadvantages of each.

Bill McLarney and Jeff Parkin give another of our accounts of work in progress in "Open System Fish Culture", in which they describe the continuation of their cage culture experiments and, as well, the series of feeding trials they conducted with fish in solar-algae ponds.

Like the article by Ty Cashman in the Energy Section, Meredith Olson's represents early feedback on the replication of some of our ideas, in this case in aquaculture, although her own considerable ingenuity is reflected as well. Her description of the trout raising experiment at Holden Village in Washington makes one wish for access to some of the trout dinners that were the result. NJT

Photo by Hilde Maingay



Open System Fish Culture - 1977

— William O. McLarney and Jeffrey Parkin

Open system fish culture at New Alchemy in 1977 involved the continuation of cage culture work in Grassy Pond (Pickerel Pond), and, in addition, a series of feeding trials similar to those described in an article by McLarney, Levine and Sherman in *Journal of The New Alchemists (3)* (1976).

CAGE CULTURE

Cage culture methods were essentially no different from those used in the previous year as described in *Journal Four*, but we attempted to grow two types of fish. Unfortunately, our efforts to raise brown bullheads (*Ictalurus nebulosus*) were aborted by almost 100% mortalities which occurred soon after handling, no matter how careful we were. Bullheads obtained locally inevitably developed what appeared to be a bacterial infection of *Pseudomonas* sp. and usually died within a few days after capture. We do not know if this phenomenon would be repeated another year or whether it is a characteristic of our local populations, or of brown bullheads as a species. In our earlier experience with the very similar yellow bullhead (*Ictalurus natalis*) in Michigan, California and Massachusetts, no disease or unusual mortality was observed, even though the fish were subjected to physiological stress as a part of our experiments. We did have trouble maintaining brown bullheads in the lab. Despite the setback, we retain the conviction that the bullheads will ultimately prove among the most useful fishes for the home grower.

Those cages not devoted to short-lived bullhead experiments were stocked with a mixture of bluegills (*Lepomis macrochirus*) and "hybrid bluegills" (♂ *Lepomis cyanellus* x ♀ *L. macrochirus*). As in 1976, trials were conducted in which some caged populations were fed Purina Trout Chow$^{(R)}$, while others received a 100% natural foods diet. The rate of growth was compared. The only difference from the previous experiment was that we had a more consistent supply of appropriate sized earthworms, due to having a new worm culture facility at New Alchemy.

In a parallel experiment, we attempted to combine the ecological and economic advantages of natural feeds with the convenience of prepared dry feeds. Jeff Parkin, whose sophisticated food-processing equipment included a solar dryer, an ordinary kitchen oven, an electric blender (for earthworm puree), a hand-operated grinder and a caulking gun, was kept busy concocting blends of alfalfa, comfrey, soy meal and earthworms, which were dubbed "Brand X" or "Jeff-Pie." The first problem to be overcome with these feeds was to make them more attractive to the fish; they fell short of commercial feed with respect to texture, color and flotation. The fish eventually did learn to take them, but seldom with the enthusiasm we should have liked to see.

The results of the cage culture trials do not demand a presentation as detailed as that given in *Journal Four*. We continue to be disappointed in the growth and production of our sunfish, though we are encouraged to note that the fish on natural foods grew 21.7% more than those on the commercial diet. The best blend of "Brand X" (45% worms, 35% soy, 10% alfalfa and 10% comfrey) produced only 75% as much growth as the commercial diet.

No differences in growth between bluegills and hybrids were apparent, though the hybrids did seem to "fill out" better, producing a more attractive table fish. On the other hand, most observers preferred the taste of bluegills to that of hybrids.

Unlike the previous year, 1977 saw high water in Grassy Pond throughout the summer and fall, and environmental conditions in the cages appeared well suited to sunfishes. Yet all the fish went noticeably "off feed" from late summer on. Our problems were briefly mentioned in an article in *The Commercial Fish Farmer Magazine* (McLarney and Todd, 1977), which brought an offer of assistance from one of the pioneer hybrid sunfish culturists, Francis Bezdek of Aquatic Management, Inc., Lisbon, Ohio. Rather than expound on our ignorance, we will postpone further discussion for another year, by which time we will have had a chance to incorporate some of Mr. Bezdek's suggestions.

FEEDING TRIALS

The feeding trials were carried out in a battery of twelve 66-gallon solar-algae ponds located in the solar courtyard adjacent to the Ark. Tilapia (*Sarotherodon aurea*)[1] were chosen for the trials, partly to maintain continuity with earlier experiments (McLarney, Levine and Sherman, 1976) but also because of their hardiness and general excellence as a research animal.

The thrust of the feeding trials, as in the cage culture experiments, was to find a low-cost, ecologically-sound substitute for fish meal which is the principal protein ingredient of commercial fish feeds. The rationale for this has been discussed in *Journal Four* (McLarney, 1977) and in the summer workshops given by the authors.

As in the earlier study, a "standard" feed composed of grains (75% rolled oats and 25% roasted soy meal) was used as a basis of comparison. As a consequence of their environment, all the fish had access to phytoplankton as food, as well. As it seems impossible to control the intensity of phytoplankton blooms in solar-algae ponds, the best we could do was to monitor population density by the rather crude method of frequent Secchi disc readings and attempt to relate that information to growth rates. Although the mean Secchi disc readings for individual solar-algae ponds varied greatly (from 11.5 to 31.7 inches in one two-week trial, and from 16.4 to 36.8 inches in another, for example) no correlation was found between phytoplankton population density and growth rate.

The experiments carried out were intended as no more than pilot studies to suggest the most productive avenues for further research. Consequently, only a brief description and a summary of the data are given below, with no attempt at statistical analysis.

The first two-week trial sought to compare the food value of the "standard" soy-oat mixture to commercial feed (Purina Trout Chow $^{(R)}$). A control series of fish received no feeding, but relied on phytoplankton for maintenance and growth.

Table 1 points out the superiority of commercial trout feed to the soy-oat mixture. It also confirms that phytoplankton had some food value for small tilapia.

Previous experiments (McLarney, Levine and Sherman, 1976) showed very significant improvement of tilapia growth when the soy-oat mixture was supplemented with midge (*Chironomus tentans*) larvae in amounts comprising 2% or 10% of the grain diet. The same approach was taken using minced fresh earthworms (*Eisenia foetida*) in place of the midge larvae (Tables 2 and 3).

In the earlier experiments with midge larvae a greater difference was seen in the growth of fish weighing less than 5 grams at the start of the experiment than in larger fish. Accordingly, in a second trial, such fish were considered separately as well as together with the others (Table 3).

It appeared that the earthworm supplement was effective in augmenting growth, but not nearly as effective as midge larvae had been in the earlier trials. Before going on, it was decided to do another set of

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[1] Those scamps, the taxonomists, are at it again: And we were so pleased to have a fish whose scientific name was the same as the colloquial name. But they've gone and placed most of the species in the old genus *Tilapia* in the genus *Sarotherodon,* including our old friend *aurea.* To the lay reader: Taxonomic names really do serve to alleviate confusion – most of the time. Should you care, the "official" common name for *S. aurea* is "blue tilapia."

trials with midge larvae in the same experimental system. This time, the soy-oat mixture, supplemented with midge larvae, was tested against two other diets – commercial trout feed and dried comfrey *(Symphytum pereginum)* plus midges. Comfrey was selected because it appeared to be well suited to cultivation as a food for herbivorous fishes, being productive and high in protein and vitamins. On a production per acre basis, comfrey contains seven times as much protein and eight times as much carbohydrate as soybeans. It also is the only known land plant, as of 1976, to synthesize the very essential vitamin B12. Adult tilapia at New Alchemy relish fresh comfrey, but we had yet to make use of the powdered dried form.

Nutritional content notwithstanding, dried comfrey was not an acceptable substitute for the soy-oat mixture (Table 4). The fish were slow to learn to eat it, never fed eagerly on it, and grew poorly on the comfrey-midge larvae diet. Further, in water, dried powdered comfrey almost immediately disintegrated to make "tea", which in turn seemed to suppress phytoplankton growth.

The soy-oat mixture, supplemented with midge larvae, still fell short of the "complete" diet represented by commercial trout feed.

TABLE 1. Growth of young blue tilapia in solar-algae ponds when fed on commercial trout feed or soy-oat mixture at 2% of body weight/day.

Diet	Control (no feed)	Soy-oat mixture	Trout feed
No. of fish	24	24	18
Mean initial wt. (grams)	6.51	7.71	6.66
Mean final wt.	6.69	9.58	9.53
% gain	2.75	24.22	43.04

TABLE 2. Growth of young blue tilapia in solar-algae ponds when fed on soy-oat mixture at 2% of body weight/day, supplemented with minced earthworms in amounts equal to 2% or 10% of the soy-oat diet (first of two trials).

Supplement	No worms	2% worms	10% worms
No. of fish	23	18	24
Mean initial wt. (grams)	3.17	2.97	3.14
Mean final wt.	4.84	4.73	5.01
% gain	53.15	59.36	59.42

Photo by Hilde Maingay

TABLE 3. Growth of young blue tilapia in solar-algae ponds when fed on soy-oat mixture at 2% of body weight/day, supplemented with minced earthworms in amounts equal to 2% or 10% of the soy-oat diet (second of two trials). Data for fish weighing less than 5 grams at the start of the experiment are shown in parentheses.

Supplement	No worms	2% worms	10% worms
No. of fish	21 (16)	24 (13)	24 (12)
Mean initial wt. (grams)	4.68 (3.23)	5.22 (3.57)	5.35 (3.44)
Final Wt.	5.68 (4.15)	6.70 (4.78)	7.01 (4.90)
% gain	21.39 (28.37)	28.09 (34.05)	30.90 (42.37)

TABLE 4. Growth of young blue tilapia in solar-algae ponds when fed a "complete" commercial diet, a soy-oat mixture supplemented with midge larvae in amounts equal to 10% of the soy-oat diet, or dried powdered comfrey similarly supplemented

Diet	Comfrey plus 10% midges	Soy-oat mixture plus 10% midges	Commercial trout feed
No. of fish	24	18	24
Mean initial wt. (grams)	8.20	7.59	7.83
Mean final wt.	8.61	10.02	10.89
% gain	5.03	31.99	38.99

TABLE 5. Growth of young blue tilapia in solar-algae ponds when fed commercial trout feed, a supplemented soy-oat mixture, or a supplemented soy-oat-earthworm mixture at 2% of body weight/day.

Diet	Soy-oat mixture plus 10% midges	50% soy-oat mixture, 50% minced fresh earthworms, plus 2% midges	Commercial trout feed
No. of fish	24	18	24
Mean initial wt. (grams)	10.35	9.84	10.60
Mean final wt.	11.70	11.79	12.67
% gain	12.96	19.75	19.54

In the final series of trials, carried out just before water temperatures became too cold for growth in tilapia, a feed mixture containing both worms and midge larvae was tested. The logic is as follows:

Midge larvae have previously been shown to increase significantly the growth of young tilapia when added to the diet in very small quantities (McLarney, Levine and Sherman, 1976); it has been suggested that the basis for this is a vitamin, amino acid, enzyme or other substance needed in only small amounts. It is easy to raise *C. tentans* larvae in quantities suitable for this purpose and New Alchemy has an established midge culture system (McLarney, 1974; McLarney, Levine and Sherman, 1976). However, it would not be feasible to raise them in quantities sufficient to constitute a major protein source for cultured fish.

It was suggested by an earlier trial in this series that earthworms in small quantities do not exert a growth-promoting effect comparable to midge larvae. However, as they are high in protein (as much as 71.5% of their total dry weight) and can be cultured in quantity, they might constitute an acceptable substitute for the ecologically and economically expensive animal protein components, principally fish meal, of commercial fish feeds.

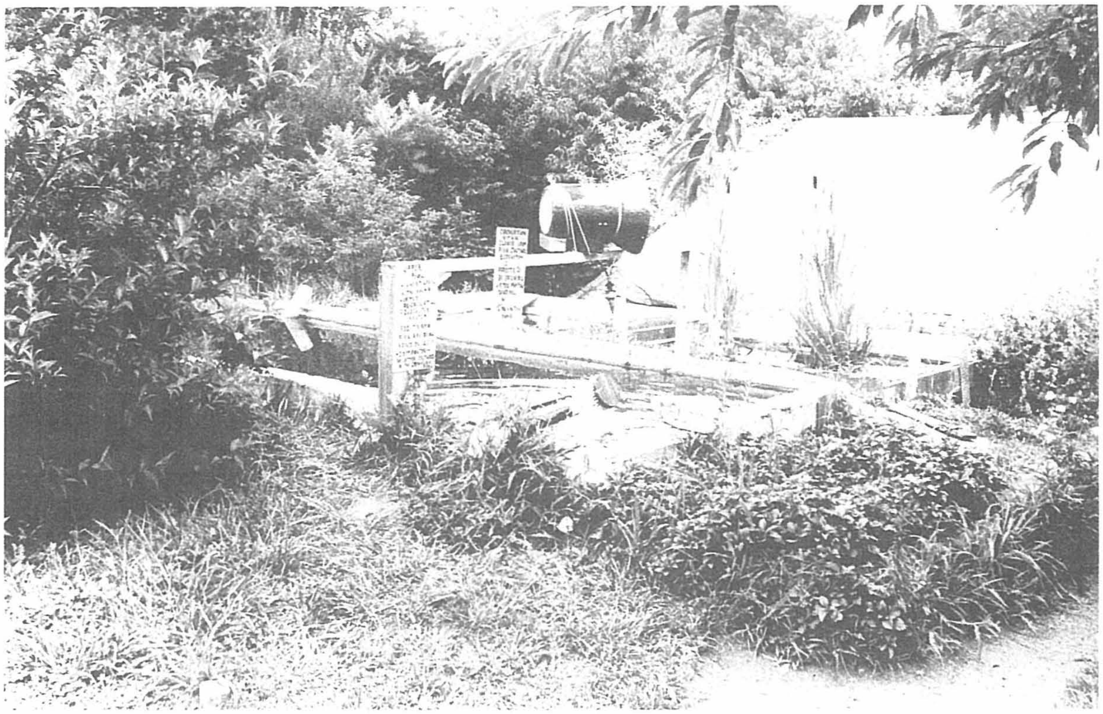
Accordingly, a diet was tested in which approximately 50% of the protein, naturally supplied by fish meal, normally present in commercial trout feed was replaced by fresh minced earthworms and the other half of the diet was supplied by the soy-oat mixture. This was supplemented with midge larvae at the rate of 2% of the total diet. This feed was tested against two feeds used in earlier trials — commercial trout feed and the soy-oat mixture, supplemented with midge larvae at 10%. Results obtained with the soy-oat-worm-midge diet were virtually identical to those obtained with trout feed (Table 5).

We wish to reemphasize that these are only pilot studies and need replication. They do suggest that an acceptable substitute for costly fish feeds might be developed by substituting earthworms for the fish meal component, midge larvae for the synthetic vitamin package and a simple grain mixture for the much more complicated blend of additional ingredients. Such feeds could be produced, in small lots at least, on an on-farm basis and at low cost, with no associated ecological disruption.

We have already begun limited indoor replications of the last trial reported, and we will expand the work as soon as weather permits. We are also expanding our worm culture and seeking funds for a full-scale investigation of cultured earthworms as a fish food or feed ingredient.

ACKNOWLEDGEMENTS:

Virtually all the full time New Alchemists rendered assistance at one time or another, as did various volunteers, notably Geoff Booth. We especially want to thank Bill McNaughton for his contributions to not only the experimental work, but design of the experiments and maintenance of the systems.



Investigations of Semi-closed Aquatic Ecosystems

– Ron Zweig

A small aquatic system represents a miniaturization of an intricate network of biological phenomena. Several semi-closed aquatic ecosystems have been constructed and are in operation at New Alchemy. Our original goal was to develop a system that would enable a family or small group to raise a portion of their own food simply and economically with minimal impact upon neighboring ecologies. The designs incorporated the use of renewable energy sources, primarily solar energy, water conservation and biological purification. The increasing pollution in rivers and lakes prompted us to devise an aquaculture that would use and reuse small quantities of fresh water.

We have begun monitoring and evaluating our aquatic food production techniques in the attempt to determine their usefulness. We are on the threshold of developing models that can prescribe management techniques for optimizing food productivity. It is our intention to study the physical and chemical parameters of the systems and, at the same time, attempt to define indicators discernible by the human senses.

Electronic sensing and chemical assay methods will be used to develop a data base for a computer model that will increase our understanding of the systems and help in predicting potential problems. The technical equipment is currently being used for research and investigative work, which, in time, will be translated into a guide for aquaculture.

The initial work involved monitoring the dome aquaculture pool in the summer of 1976.[1] Further monitoring was done there in the summer of 1977, as well as in the closed-loop system (formerly called the Miniature Ark), the Six-Pack pool and the solar-algae ponds. The solar-algae ponds are being evaluated intensively. These translucent, fiberglass cylinders, five feet in diameter and in height, have proved extremely effective as fish culture systems and as passive solar collectors.[2]

I. The Closed-Loop System

The latest experiments with the system we used to call the Miniature Ark have involved a change in the components.[3] The three pools are still connected to form a circular "river." The water is circulated by a sail-wing windmill connected to a water pump made from a trailer tire. (See "The New Alchemy Sailwing" - page 31). An auxiliary electric water pump is also used. In the summer of 1977, the biological filter was removed and phytoplankton was used for the conversion of toxic fish wastes into fish food.

In the past, the two smaller upper pools were used for raising live fish feeds and for water purification. The lower one was the polyculture pool, containing the fish. In 1977, the fish were housed in the two upper pools. The lower one was converted to a resource pool for growing zooplankton and for the natural recycling of fertile fish water nutrients. The

Photo by Ron Zweig

idea was that the larger pool would function like a natural pond so that the method could be extrapolated to a natural lake where a windmill would pump lake water and nutrients to pools on the bank in which fish would be cultured. The used water would be returned to the lake. Another change in our system in 1977 was that we removed the structures covering the upper pools but left the greenhouse over the lower pool intact to allow for heat retention and to extend the growing season within.

We mounted a Will-o-the-Wisp (R) electric bug light collector above the upper pool. It was operated at night to trap insects, providing the fish with additional food in the form of live insects. Not only the fish enjoyed the captured insects. Occasionally a migrant frog would find its way into the upper pool and spend the night expectantly beneath the light, waiting for direct delivery of insects into its mouth. The frogs were evicted on discovery.

We obtained additional fish food with a modification of a simple fly trap designed at the Farallones Institute's Integral Urban House in Berkeley, California. The trap was made from a piece of aluminum window screen shaped into two independent cones about one foot in diameter. One was about ten inches in height, the other about five. The smaller one, which had a one-inch hole cut at the peak, was placed inside the taller and attached at the perimeter with clothespins. The pins made a pedestal about one and a half inches off the ground, making entrance space for flies. The trap was placed over bait, generally supplied free of charge by the neighboring dog population, although bits of fish waste proved a superior attractant. The flies flew to the bait. Once in the trap, they moved upward toward the light at the hole in the smaller cone and, once through the hole, were caught between the screens. At the end of a summer day, it was not unusual to find up to 150 trapped flies which were released into the pond.

Experimental Trials

Trial One

There were two trials, each with a predominant species of fish. The brown bullhead, *Ictalurous nebulosa,* was used in the first and *Tilapia aurea* in the second. The bullheads were seined from a densely-populated local pond that contained many fish of nearly uniform size. Their growth may have been stunted due to the large population in the pond. Two hundred fish were put into the upper pool of the closed-loop system and one hundred into the lower. The total fish mass introduced was 9,561 grams (21 pounds), each fish weighing approximately 32 grams. Over the 41-day experiment, beginning on May 26, 1977, the bullheads were fed 6,270 grams of Purina Trout Chow(R) (PTC) in addition to the insects blown into the pond by the bug light, which were not quantitatively measured. Brown bullheads are mainly carnivorous. We were interested in seeing how productive they would be in the recirculating system. With the exception of six Louisiana red crayfish, *Procambarus clarkii,* added to the middle pool to aid in stirring excessive bottom sediments and to prevent the creation of an anaerobic substrate, this experiment was a monoculture.

It was discontinued July 6 when it became evident that the entire population had been infected by disease. Casualties were first observed on June 26, shortly after we had received a shipment of channel catfish, *Ictalurus punctatus,* which were put into one of the solar-algae ponds. They were probably the source of infection, which spread probably because we used instruments interchangeably among fish culture systems. Most of the channel catfish died shortly after arrival. The exact nature of the disease was never determined. Only the catfish were affected. Other species of fishes seemed immune. In the future, we plan to use the yellow bullhead, *Ictalurus natalis,* which is hardier in culture environments. It is prevalent in New England.

Despite the disease infestation, fish growth was significant. In the upper pool the fish were kept in a floating wooden frame for observation. They were fed three times daily. The fish in the upper pool received twice as much feed as those in the middle one. At each feeding up to 100 grams of floating PTC were given to the fish in the upper pool. On some cloudy days, the feeding rate was reduced and the third feeding eliminated. The gross production (including casualties) amounted to 14,928 grams (32.8 pounds) or a net production of 5,367 grams. The dry feed to wet fish *conversion ratio was 1.2*, indicating* a potentially useful production system for bullheads. The drawback lay in the reliance on commercial feed, but we have started working on growing alternative fish food. (See page 69)

Trial Two

The second experiment began on July 8, when three hundred newly hatched *Tilapia aurea* were stocked in the upper pool and two hundred in the middle one. The total weight of stocked fish for both pools was 25.5 grams. The fish were fed insects caught in the fly trap, as well as those

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* *Please note:* For comparison with the results of more traditionally reported growth conversion data, this ratio is the inverse of those reported last year. All conversion factors in these articles will be reported in this way.

blown into a bag attached to the bug light and subsequently ground. We used minimal additional commercial feeds. The fish were dependent on the resources of the closed-loop unit, which were the phytoplankton or algae and the zooplankton, the captured insects, and the detritus from the bullhead trial. A zooplankton bloom composed mostly of cladocerans and copepods occurred during July but disappeared on July 30, when half a dozen young domestic ducks were put into the middle pool. The ducks fed there and their droppings added nutrients to the system. A phytoplankton bloom occurred shortly after this, coinciding directly with the observed drop in the zooplankton population. The ducks were removed a week later because we were worried that they might be eating the small fish, which later proved erroneous as all the fish were retrieved at the end of the experiment. Their escape behavior evidently improved with the introduction of the ducks and they became much harder to capture in order to check their growth. Ducks are used extensively in aquaculture in Southeast Asia and the Far East to provide increased nutrients and add another dimension to the productivity of a system.

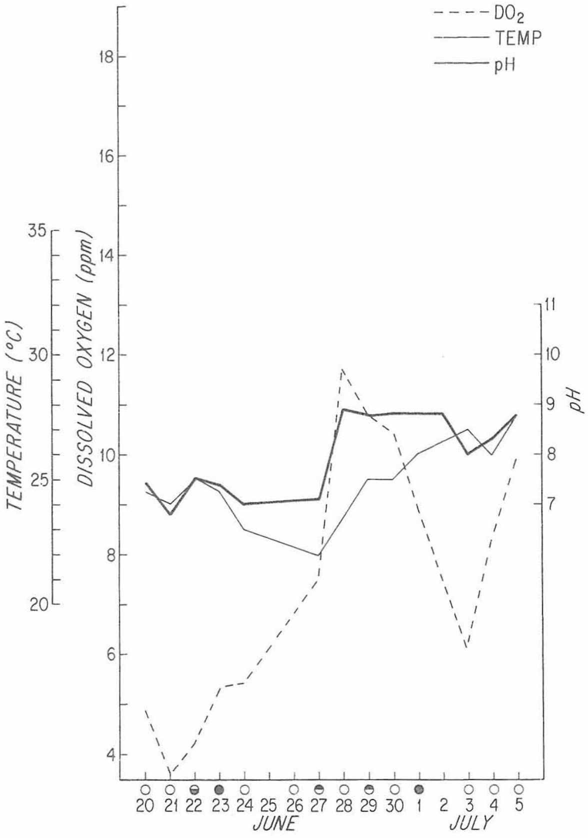
Two weeks after the trial started, a number of the tilapia were weighed. Forty-eight fish from the upper pool weighed 39.8 grams and forty fish from the middle pool 29.2 grams, a weight of 0.8 grams per fish. This was an increase of 0.75 grams per fish or a 16-fold increase after two weeks. The superior growth of the fish in the upper pool was probably due to the zooplankton that were pumped up from the bottom pool. The young fish appeared mainly carnivorous. For the first six weeks, the fish did not feed significantly on the filamentous algae although, subsequently, it disappeared quite rapidly.

The experiment ended on September 30, 1977. The water temperature had been falling below 20°C consistently for the preceding week. The fish were removed. They showed a net gain of 2,031 grams (4.5 pounds), indicating the growth possible without supplementary commercial feeds. Had older fish been used at the outset, they would have been more herbivorous and therefore more capable of exploiting the phytoplankton as well as the filamentous and other kinds of algae.

Although it did not demonstrate high productivity, this experiment provided a foundation for understanding the potential of such a system. We shall replicate it increasing the feed input which should indicate the effect of nutritional additions beyond those provided by the system. We may again add a few ducks and monitor their impact.

Daily readings were taken in the morning, at midday, and in later afternoon to measure the temperature, DO_2, and pH of each of the three pools. This was done to observe how solar energy, through photosynthesis, affected the temperature and water chemistry. Graphs 1, 2 and 3, derived from the data collected at the end of June and in early July, illustrate these. The bottom pool functioned as an oxygen reservoir for the fish during the night and on heavily overcast days. Measurements on sunny days indicated considerable photosynthetic activity in the shallower pools. Even with populations of respiring fish, the oxygen levels were as high or higher than in the covered lower pool because of the greater amount of solar energy for photosynthesis reaching them. In some instances, oxygen levels were higher after passing through the upper pools than in the bottom pond, indicating the necessity of optimizing the amount of solar energy entering an intensely productive pond. The solar-algae ponds with their nearly transparent sides maximize solar energy input. Shallow sub-surface pools may work in a similar way.

CLOSED LOOP UPPER POOL – PM



GRAPH I

II. The Dome

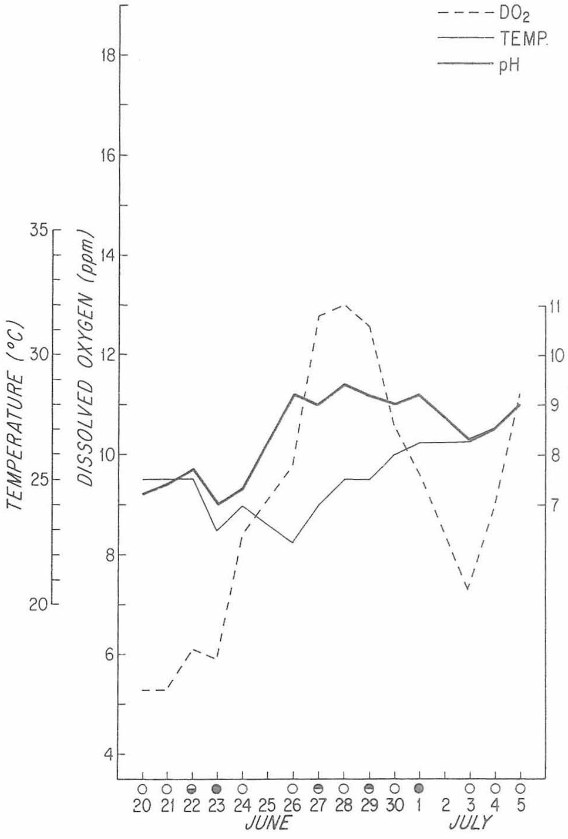
The dome system is unchanged from its description in the fourth *Journal.* [3] Beyond painting the interior of the structure and removing the sediments from the biological filter which were used to fertilize the soil inside the dome, little physical maintenance was required. As before, the pool was used for breeding tilapia.

Over three thousand young tilapia were hatched in the system. Commercial food was reduced to one-quarter of that given during the previous summer. Several vegetative feeds were supplied. A quantitative account of this material was recorded. Temperature, DO_2, and pH measurements were taken three times daily to observe the general health of the system and the effects of sunlight on its water chemistry. Graph 4 illustrates some of the daily fluctuations of the ponds over part of the summer.

We grew *Tilapia aurea* in a monoculture because we wanted to prevent other species from preying upon the newborn fry. On May 23, sixty-five adult tilapia weighing 9,071 grams (20 pounds) were put in the dome pool. Thirty days later on the summer solstice, June 21, the first newly-hatched fish were spotted and retrieved.

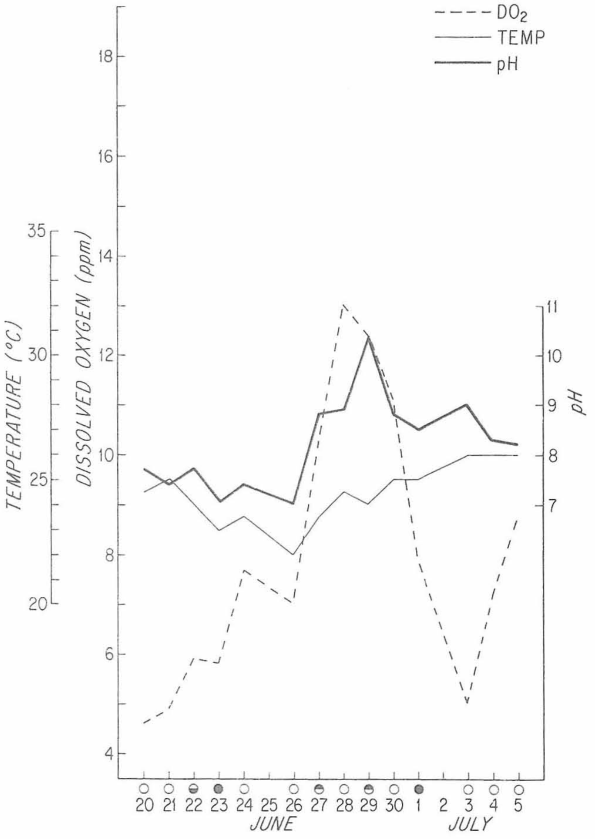
A small, cylindrical, fine-meshed basket was suspended in the pond. As fry were found swimming near the surface, they were netted out and placed in this holding cage. Some of the fish put into the cage were older and several times larger than others. Although tilapia are mainly herbivorous as adults, they are omnivorous when young. Though the fish in the cage were fed daily, they may not have been fed enough. There was some evidence of cannibalism as the number of fish in the enclosure diminished considerably. Those remaining were mostly the larger ones. We did not analyze the stomach contents of the larger fish, but we are fairly certain they ate the smaller ones. There were no holes in the basket through which they might have escaped. This made an accurate census of the number of fish hatched impossible. As Bill McLarney commented, "If something can get something else in its mouth, there is always the chance of the smaller one being eaten."

CLOSED LOOP MIDDLE POOL – PM



GRAPH 2

CLOSED LOOP LOWER POOL – PM



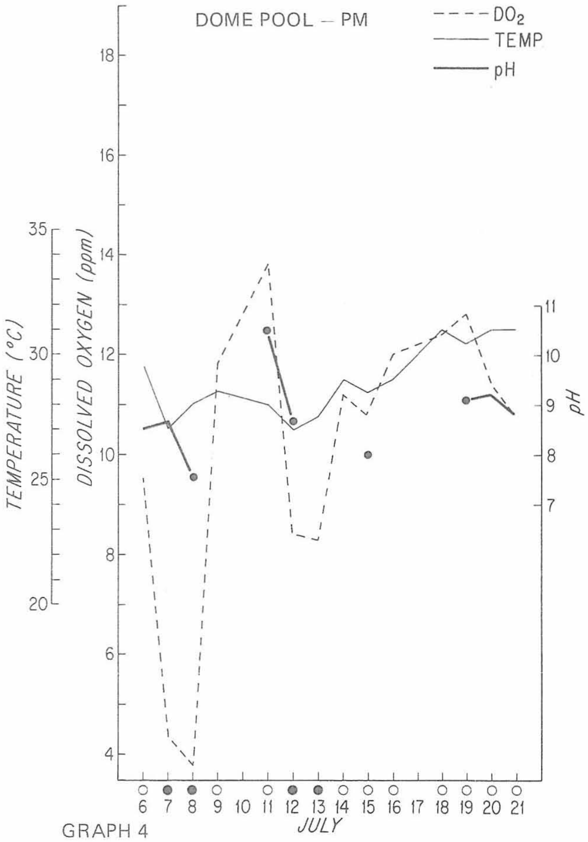
GRAPH 3

Photo by Ron Zweig

Cannibalism was suspected in one of the heavily stocked solar-algae pond experiments as well.

The fish were fed 2,810 grams of commercial feed. They were also fed 1,611 grams of the Russian Comfrey, *Symphytum peregrinum*, and 2,548 grams of hairy vetch (both dry weight), bringing the total dry feed to 6,969 grams. In mid-summer, 14 edible-size fish were removed weighing 2,002 grams. After 158 days, on October 28, 535 fish were removed. Their gross weight was 10,260 grams, bringing the total net growth to 3,190 grams. The dry feed to wet fish conversion ratio was 2.18. The commercial feed to wet fish ratio was 0.88. This is nearly one-half the efficiency of last season's trial. The amount of commercial feed per day was one-quarter that of the previous season and this could be part of the explanation, as tilapia require protein-rich nutrients for growth when young. The vegetative matter put into the pond the previous year was not measured and could have varied significantly. Yet another variable could be in phytoplankton density, although both blooms appeared similar both years. In 1977, a bloom developed on June 13, 21 days after the fish were put in the pond, and remained until the harvest at the end of October.

A comparison table of fish production data is supplied at the conclusion of the article.



GRAPH 4

III. The Solar-Algae Ponds

Over the past year, the work with the solar-algae ponds has expanded. The aquaculture facilities have increased from two prototype, five-foot diameter ponds to nine within the Cape Cod Ark and fourteen in the adjacent courtyards. (See Diagram 1.) We have been working with several strategies with regard to density and diversity of aquatic species and to the physical orientation of the ponds. The experimentation and evaluation involved production trials and the measuring of several physical and chemical characteristics.

Species Dynamics in the Solar-Algae Ponds

Several experiments were conducted with monocultures of *Tilapia aurea.* Others included the mirror carp, *Cyprinus carpio,* the grass carp, *Ctenopharyngodon idellus,* the brown bullhead, *Ictalurus nebulosus,* the Louisiana red crayfish, *Procambarus clarki,* and a local fresh water clam, *Elliptio complanata.* The last three were not cultured intensively but were tested for viability and for impact upon the ponds. The predominant phytoplankton populations which established themselves in the ponds were either *Golenkinia* sp. or *Scenedesmus* sp. Both are green algae. One or the other, usually the former, was found to be dominant, with trace representatives of several sub-dominant species. There were periodic blooms of several species of zooplankton. The necessary conditions for zooplankton blooms are not well understood. In ponds lacking predatory fish the species established were an ostracod, *Chlamydotheca* sp., two cladocerans, *Scapholeberis* sp. and *Simocephalus* sp., and the copepod, *Cyclops vernalis.* The specific factors regulating these populations are unknown. Dense populations appeared frequently and then disappeared. We are beginning a project, funded by The National Science Foundation, to evaluate the solar-algae ponds and to develop ecological models which should clarify some of the unknown factors and allow us to control and improve conditions in order to maximize productivity. The project is designed to gain an understanding of the dynamics of the whole system. We intend to view the ponds as individual living organisms, the internal complexities of which are the foundation for their "lives."

As in previous experiments the ponds began as cylinders filled with tap water. Within forty-eight hours, they were fertilized with an aliquot of human male urine.* A phytoplankton bloom occurred within twenty-four hours at temperatures between 25° and 30°C.

As in all aquatic systems the number of nutritional niches within a solar-algae pond is limited. The phytoplankton is the predominant product of the pond, making a phytoplankton feeder like tilapia ideally suited to this kind of environment. The phytoplankton provide oxygen through photosynthesis, function as micro-heat exchangers by absorbing solar energy and purify the water by directly metabolizing toxic fish wastes such as ammonia[4]. Some sedentary algal and protozoa grow on the inner surface walls of the ponds which the fish have proved adept at cropping. The mirror carp utilize their feces. We also fed the fish commercial feed and vegetative matter. Their wastes were nutrients for the phytoplankton. It has been found that, when some species of fish are grown together, greater growth results than with individual species.[5,6,7]

We decided to test brown bullheads, *Ictalurus nebulosis,* which are predominantly carnivores, in the solar-algae ponds. Although they are less efficient at cropping than herbivores, we thought they might survive in the outdoor ponds during the winter and might also assist in stirring nutrients into the water column by swimming near the bottom of the ponds. Although the bullheads were initially active and voracious, as mentioned earlier they became diseased after a shipment of channel catfish arrived.

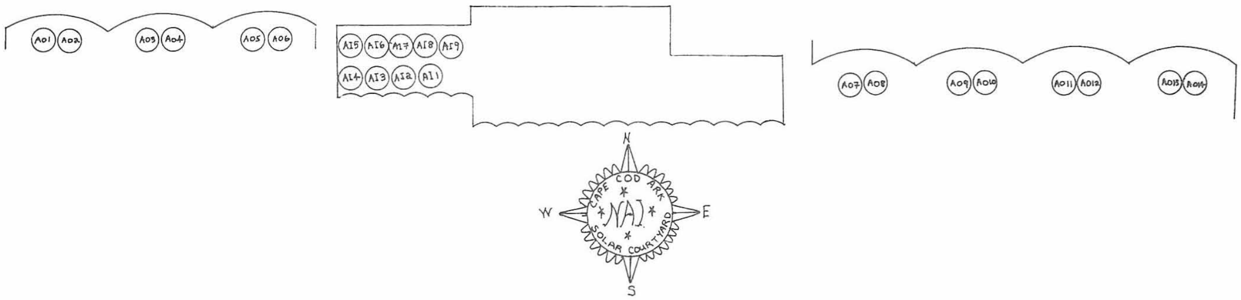


DIAGRAM 1. *This diagram illustrates the location and number of the Solar-Algae ponds in and adjacent to the Ark in the solar Courtyards. The Courtyard reflectors are made of poured concrete and painted white. The ground is covered with highly reflective white marble chips. The numbers of the ponds are indicated in their circled locations.*
AO1 indicates Ark Outside 1, and AI1 represents Ark Inside 1. The diagram is derived from a Solsearch Architecture drawing.

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* Female urine was also tested, but did not stimulate significant algal blooms. Although this is known among aquaculturists, we felt it needed testing. People having had a disease which could be transferred in urine should not contribute urine.

Local fresh water clams were introduced into the ponds and did well. Normally, this species is considered to have an undesirable, pungent flavor. After a month in the solar-algae ponds the taste was greatly improved. The clams performed a necessary biological function. They are filter feeders and generally thrive on phytoplankton. They would compete with tilapia but could be used in polyculture with non-phytoplankton feeders. In densely crowded populations, an anoxic condition can occur unless the algae is constantly cropped. The clams would allow us to use domestic fishes which are not phytoplankton feeders in the ponds. We plan to test the clam, *Corbicula* sp.

Production Trials

The productivity experiments this year used both monoculture and polyculture strategies. They were done both in single, independent solar-algae ponds and in pond couplets linked with simple, air-driven pumps and siphons[2] which exchanged water between the two ponds at night. Some of the experiments involved minimal supplementary feeds and others intensive daily feeding. Because we had many ponds and a limited stock of over-wintered fish, we began the summer with low density trials. Nine trials were run, all without filtration. Eight were monitored two to three times daily. Measurements of DO_2 concentrations, temperature and pH were recorded. The ninth was monitored constantly with a multipoint chart recorder. (See page 105)

Monoculture Experiments using *Tilapia aurea*

Experiment 1. Three hundred and eighty newly hatched *Tilapia aurea* were put in a solar-algae pond located in front of a reflector on the rim of the hill near the garden.[2] Two hundred and fifty tilapia were added on July 15 and more at different times until August 13, bringing the total weight of the fish to 93 grams. The fish were fed commercial feed exclusively (PTC) to a total of 1,242 grams during the 136 days of the experiment, which was terminated on November 29, 1977. The three hundred and fifty-nine surviving fish weighed 1,091 grams, an increase of 998 grams. The dry feed to wet fish conversion ratio was 1.24.

This pond was aerated intermittently by a small, wind-driven air pump attached to a Savonius Rotor windmill[9]. Otherwise, an electric air compressor was used nocturnally.

Experiment 2. This experiment used coupled ponds (AO*3* and *4*) (see diagram) in the center reflector of the Ark's west courtyard. Five hundred tilapia fry were placed in pond AO*3* on July 20, 1977. The fish weighed a total of 82 grams. The experiment lasted 132 days, until November 29. At one point during the experiment, the siphon between the tanks became clogged and about one-third of pond AO4's water was lost. Pond AO*3* overflowed and twenty-one fish escaped. They were found on the ground the next morning. At the end of the trial, two hundred and ninety-five fish were found in the pond, accounting for a total of three hundred and sixteen fish. Perhaps some of these fish died and decomposed on the bottom but this is unlikely since survival of this species in the other solar-algae ponds was better. The other cause could have been cannibalism as seemed to have been the case in the dome. There was a difference in relative size of the fish when they were stocked.

During the trial, the fish were fed 1,096 grams of trout chow. The total fish production was 1,270 grams for a net increase of 1,188 grams. The dry feed to wet fish ratio is difficult to compute due to the twenty-one lost fish. Existing data allows for a conversion of 0.92. This relatively high efficiency could be due to feeds available in the complementary pond. A zooplankton bloom did not occur although it was seeded with a cladoceran, *Scapholeberis* sp.

It is difficult to compare this experiment to the first one because of the lost fish. The resources available in the complementary pond allowed for some increased growth. These experiments do not justify using a coupled system but, with greater quantities of supplementary feeds, the system may yet prove useful. There are still design considerations which have not been tested.

Experiment 3. This was a monoculture trial of *T. aurea* conducted in an uncoupled solar-algae pond located inside the Ark. (See diagram, position AI3.) The fish were fed a more intensive diet of commercial feed than in the two experiments already described. The pond was aerated at night. The experiment began on August 1, 1977. Two hundred and fifty fish weighing 44.5 grams were put into the pond. During the trial ending December 5, they were fed 3,607 grams of commercial feed. On that day, the fish weighed a total of 3,919 grams, a net increase of 3,874.5 grams. The dry feed to wet fish conversion ratio was 0.93. A nearly one to one ratio is usually the efficiency for commercial feeds.

This system required more careful management than the others because greater feeding resulted in a build-up of sediments from fish wastes. As a result, concentrations of toxic ammonia beyond the utilization capability of the phytoplankton were released into the system. Sediments had to be pumped out weekly to prevent the development of anaerobic conditions in the lower layers of the sediment and reduce the chance of emission of toxic sulfides into the water.

When the tap water was first added, the pond was clean but not sterile. There was some organic matter remaining from a previous trial which apparently contained dormant zooplankton eggs, for, after the water had been standing for a couple of weeks but before the fish were added, a bloom of the Ostracod, *Chlamydotheca* sp., occurred. The zooplankton were large enough to be seen swimming in the pond and initially seemed too large for the fish to eat. The two populations coexisted for ten days. The zooplankton disappeared at the end of that time. Either the fish consumed the zooplankton or made the water chemistry intolerable for the zooplankton.

Polyculture Experiments using *Tilapia, Mirror Carp* and *Grass Carp*

Experiment 4. This was the first polyculture experiment last spring. The same solar-algae pond as used in Experiment 1 was used in this trial. The tank had an acrylic top. On April 14, 1977, one hundred sixty-three tilapia weighting 751 grams and one mirror carp weighing 220 grams were put into the pond. The effect of this one carp on the growth of the population was compared to growth in tilapia monocultures. The fish were fed dry weight equivalents of 2,553 grams of trout chow, 317 grams of comfrey and 228 grams of *Azolla* sp., a tropical, floating water fern. The experiment lasted ninety-two days and was terminated on July 15, 1977. Commercial feed was given in equal amounts each day. There was a steady increase in the amount of vegetative matter given, based on the demand of the fish. At the end of the trial, one hundred and forty-nine tilapia and the mirror carp were weighed at a total of 3,940 grams, a net increase of 3,093 grams. The total dry feed to wet fish conversion ratio was 1.0. The commercial feed to wet fish conversion ratio was 0.82, indicating that the vegetative matter likely incurred fish growth comparable to prior solar-algae pond experiments that used commercial feed exclusively.

The fish for this experiment were all at least eight months old at the outset. They were mature enough to use the plant material as efficiently as they did the animal protein in the commercial feed. This would indicate that more efficient designs in regard to fish age and size would minimize the commercial feed component of their overall diet for efficient growth. During the last portion of the experiment, the bottom sediments were pumped out periodically. At this time, ammonia levels from the waste material accumulated on the bottom were as high as 3 ppm. These residues were used to irrigate the surrounding garden area which included comfrey plants that were fed to the fish.

The mirror carp had no detectable effect on overall productivity, as production was the same as in tilapia monoculture. This experiment best indicates the potentiality of vegetative feeds.

The DO_2 recordings of this pond at no time indicated a condition stressful for the fish. The pH levels were measured toward the end of the experiment and were generally found to be between 7.0 and 9.0. They rarely went higher, although, in a few instances, they did go as high as 10.2. The pH fluctuations of the water may be significant because high pH increases the toxic un-ionized ammonia relative to ionized ammonia and may also decrease the digestion efficiency of the tilapia.

Experiment 5. This was the first use of coupled solar-algae ponds containing several species of fish to determine productivity. The ponds were in the east courtyard of the Ark. Six ponds were used, four in coupled pairs and two independently. Phytoplankton blooms were established using the method described earlier. The idea was to establish populations of different species of fish equal in proportion to the amount of water used. The two independent ponds were set up with half the population of fish as those in the coupled systems. Small densities of fish were used. The following chart outlines these populations.

TABLE I. STOCKING DENSITY DATA

Courtyard		Fish Weight (grams)/Number		
Pond Number	Date Fish Introduced	*Tilapia aurea*	Mirror Carp	Grass Carp
AO7	6-21-77		102/15	
	6-27-77	40/7		
	7-12-77			24.5/15
	7-15-77	555/20		
AO*8*	6-21-77		108/15	
	6-27-77	40/8		
	7-12-77			24.5/15
	7-15-77	515/19		
AO*9*	6-21-77		174/30	
	6-27-77	80/14		
	7-12-77			47/30
	7-15-77	1415/52		
AO*10*	Without fish coupled to AO*9*			
AO*11*	6-21-77		176/30	
	6-27-77	80/14		
	7-12-77			53.2/30
	7-15-77	1135/52		
AO*12*	Without fish coupled to AO*11*			

The fish were fed in proportion to pond population. Ponds AO7 and *8* received half as much as ponds AO*9* and *10*. Foods were trout chow, comfrey, vetch and purslane. Commercial feed was given in daily allotments; vegetative matter as it was consumed. Table II illustrates the quantity and kind of feed given to the fish during the one hundred and nineteen days of the experiment.

TABLE II. DRY WEIGHT FEEDS (GRAMS)

Courtyard Pond Number	Purina Trout Chow$^{(R)}$	Comfrey	Vetch	Purslane	Total
AO7	1,067	598	125.9	16.2	1,807.1
AO*8*	1,067	620.3	124.5	19.6	1,831.4
AO*9*	2,134	1,248.4	245.6	26.3	3,654.3
AO*11*	2,134	1,045.9	233.8	26.7	3,440.4

The idea in keeping one of the pair of ponds free of fish was to allow a zooplankton population to become established in the fish-free pond. The ponds were aerated nocturnally at which time there was some water exchange between the two. For a two-week period, there was a dense population of the cladoceran, *Scapholeberis* sp., in pond AO*10*. Samples were transferred to AO*12*; but a bloom did not develop in this pond. Why the zooplankton bloomed in AO*10* but not in AO*12* was never determined. The quality of the water seemed similar.

One aspect of the coupled system proved beneficial. Sediments from both ponds tended to build up in the one without fish which, however, did have a couple of crayfish for stirring up the bottom. To remove bottom sediments required draining water from just one of the ponds.

This series of trials ended on October 18, 1977. Table III lists the production figures and the conversion ratios.

TABLE III. GROWTH DATA

Courtyard Pond Number	Net Production (grams)/Number Fish				Conversion ratio (Dry Feed/ Wet Fish)
	Tilapia	Mirror Carp	Grass Carp	Total	
AO7	746/27	99/15	14.5/11	869/53	2.1
AO*8*	924/26	101/7	26.4/6	1,051/39	1.7
AO*9*	1,780/67	93/22	--	1,826/89	2.0
AO*11*	1,819/58	208/30 (Dead)	--	2,027/88	1.2

Although results are somewhat erratic because not all the fish were retrieved, it seems the coupling strategy does not significantly increase productivity. From the tilapia data, it appears that the tilapia grew predictably in relation to their number and the quantity of feed given them. Dense zooplankton cultures would have to have been established in the fish-free ponds to have an appreciable impact on productivity. We did gain in understanding of the water chemistry in solar-algae ponds and its potential effect upon fish growth.

Water Chemistry Evaluation in the Coupled Systems

The translucent sides of the solar-algae ponds allow considerable solar energy to penetrate the water, greatly enhancing photosynthesis. This increases potential primary productivity in comparison to a sub-surface pond. However, a deleterious effect from intense biochemical activity became apparent through this series of trials. Oxygen, which is a product of photosynthesis, is crucial to the respiration of most of the organisms including the fish. The ponds regularly achieved supersaturated concentrations of dissolved oxygen. At 30°C, concentrations above 20 ppm were measured. At this temperature, fresh water at sea level is saturated at 7.5 ppm.[10] The higher the water temperature, the lower the amount of oxygen it can hold. The algae and other organisms in the system may affect the saturation levels. It has been reported that the tissues of fish also become saturated.[11] As water temperature increases, excess oxygen can bubble out of the water at super-saturated concentrations. This has been found to be true in fish tissues as well.[11] On August 8, 1977, all the carp in pond AO*11* died. All the tilapia survived. It seems the carp suffered from the high oxygen levels as the temperature in the pond rose. Tilapia may have higher metabolic and respiratory rates at these temperatures, permitting them to utilize the extra oxygen rather than its causing bubbling in their tissues. All other measured water quality factors appeared within a safe range. Why this occurred is not known. There is a relatively simple means of alleviating the problem. By bubbling air intensively through the water mass, the volume can be sufficiently disrupted to eliminate excess oxygen. As this affects management procedures, the solution may be as simple as aerating on hot, sunny days. However, controlling the levels of dissolved oxygen is a consideration in working with large masses of respiring fish in warm months.

Another problem resulting from intense photosynthetic activity concerns the pH of the system. In an initial attempt to work with the simplest systems possible, we did not equip the ponds with a buffering component. As a result, all the carbon dioxide and bicarbonates in the water that contribute to the acidity of the system are used for photosynthesis and the pH is driven upward.[12] Afternoon pH levels in solar-algae pond systems have been as high as pH 12. Graphs 5, 6 and 7 of ponds AO7, *9* and *10* respectively, illustrate the pH, temperature and DO_2 of a segment of this experiment. The pH in these ponds was frequently above 9.0. Moriarty[13] found that *Tilapia nilotica* were able to lower the pH in their stomachs to approximately 1.4 during the morning. This permitted lysing or breaking down the algal cell walls to make the nutrients within available for digestion. In our experiment the fish may have been too stressed by the high pH to adjust their stomachs to the pH level appropriate for digestion. This, in turn, would have lowered their digestive capability. If this digestive reaction is not restricted to time of day and is affected by environmental conditions, then maintaining the system at a more neutral pH may increase digestive efficiency in the fish.

In Experiment 4, the overall mass of the fish was greater than in Experiment 5. This could have contributed to lower pH readings in two ways. The first could be that there were higher quantities of carbon dioxide in the system as a result of more respiration. Also, the fish released more waste that was utilized by respiring bacteria that, in turn, released carbon dioxide and organic acids.

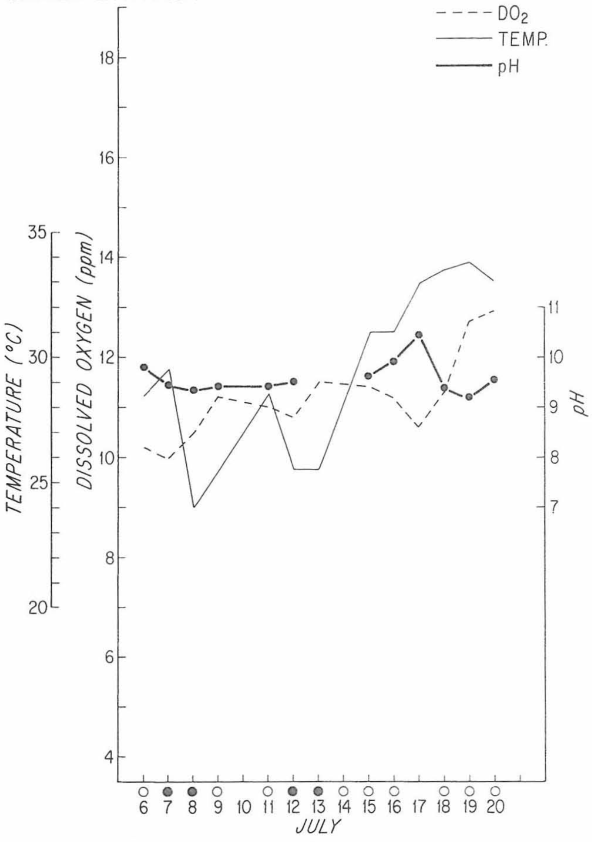
Spotte[14] reports that the higher the pH, the higher concentrations of toxic un-ionized ammonia relative to ionized ammonia. High rates of algal metabolism coinciding with high pH levels may alleviate this by removing ammonia. Ammonia was not detected in any of the ponds in Experiment 5. We are presently investigating appropriate methods to buffer pH downwards.

Thermal Energetics of Solar-Algae Ponds

The solar-algae ponds have a secondary function as passive solar collectors. Graph 8 illustrates the maximum and minimum water temperatures of ponds inside and outside the Ark as well as the inside and outside maximum and minimum air temperatures from December 21, 1977, to January 17, 1978. This period covers the shortest day of the year. During that time, the average temperature fluctuation per day in one pond located inside the Ark was 2.4°C (4.4°F). This amounts to an average contribution of 228,000 BTU of thermal energy to the Ark's internal climate per day for all nine 630-gallon ponds. Fuel oil No. 2, which is commonly used for heating, has a thermal capacity of about 139,600 BTU per gallon. The cost for the winter of 1977/78 on Cape Cod was about $0.50 per gallon. As new oil furnaces have an overall efficiency of about 50 per cent, this brings the potential useful heat derived from each gallon of oil down to about 111,680 BTU. At this rate the solar-algae ponds inside the Ark contributed the equivalent of approximately two gallons of oil heat or a dollar per day during this period.

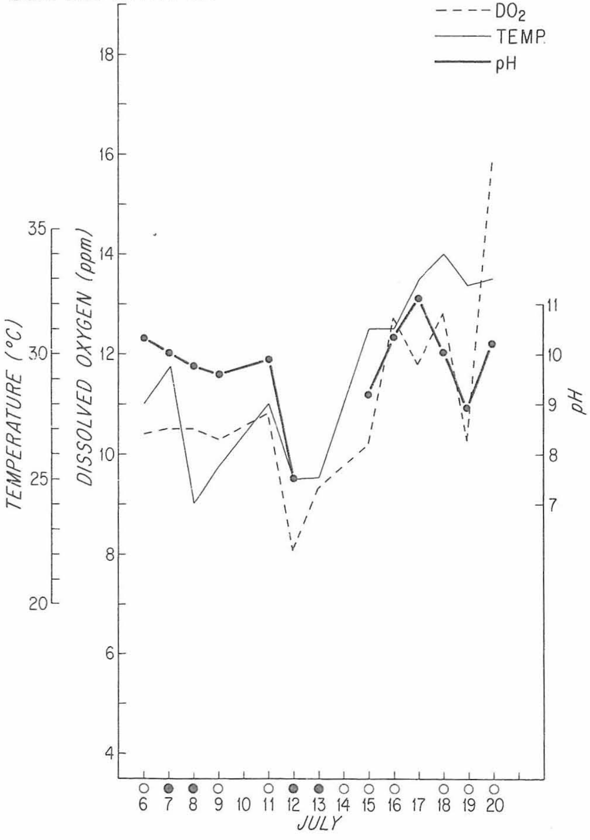
During the middle of November, 1977, the average diurnal temperature fluctuation of these ponds was 12.5°F, a collection and release of about 652,000 BTU. In terms of incident solar radiation, the equivalent time period after the solstice is the beginning of February, close to mid-winter. If the cloud cover is similar, an equivalent amount of generated heat should be expected amounting to about 5.8 gallons of fuel oil or $2.90 worth of fuel per day on the Cape during the cold months. The overall impact of the thermal dynamics of this aquaculture system will be evaluated within the next year. The results indicate a valuable secondary aspect to the aquaculture design.

OUTSIDE SOLAR POND NO. 7 – PM
SINGLE WITH FISH



GRAPH 5

OUTSIDE SOLAR POND NO. 9 – PM
COUPLED WITH FISH



GRAPH 6

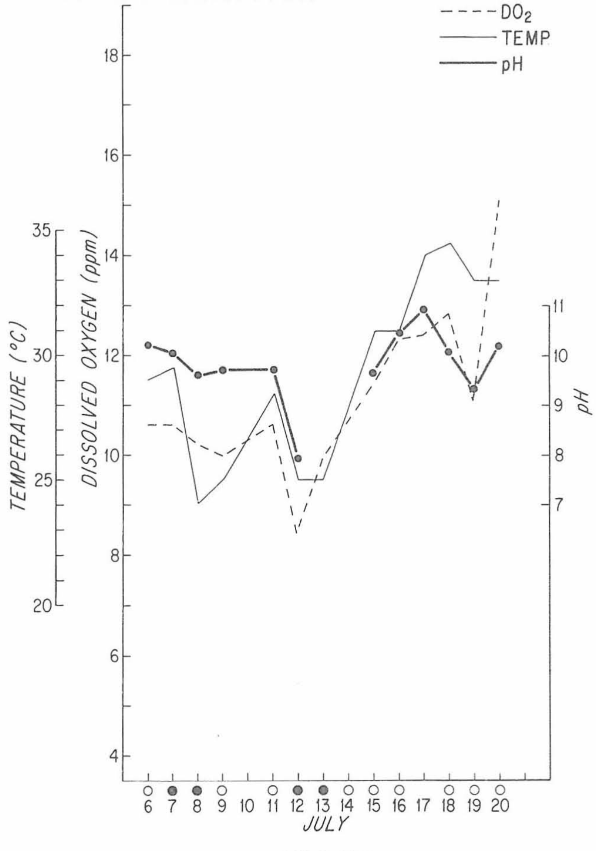
Summary of Semi-Closed Aquatic Systems

The work described has given us considerable information about the dynamics of semi-closed aquatic systems. Many of the experiments with small quantities of supplementary feeds resulted in low productivity, indicating that food is a major potential limiting factor of such systems. In the intensive feeding trials, we achieved results similar to those of the previous year. In the case of the closed-loop system, we can now estimate productivity from a population of newly-hatched tilapia using few outside inputs.

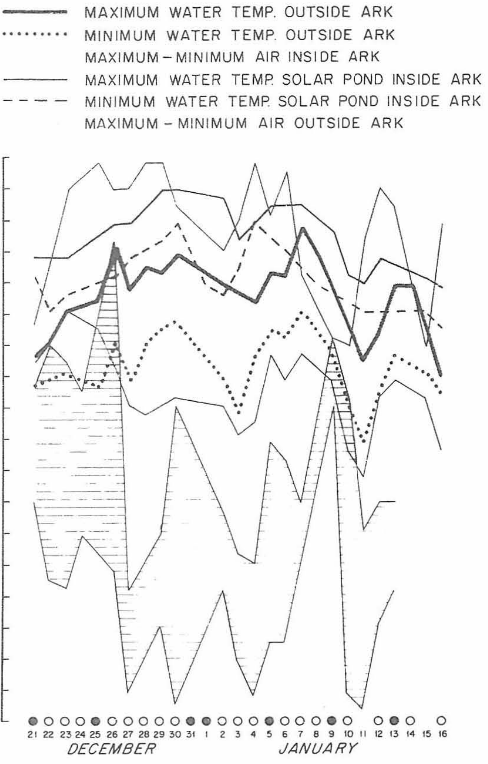
The experiments with the solar-algae ponds demonstrated several factors that affect fish growth. High pH seems to be a major limiting factor. Next season we shall try to alleviate this problem. We plan to conduct more intensive experiments with density and species of fish and also to increase supplemental feeds.

We have several other ideas we plan to implement. One is to use the upper surfaces of the solar-algae ponds for hydroponics and to stock carnivorous species to drive the system. Such a pond would be coupled to one containing herbivorous carp and tilapia. The two could be linked to a third smaller one containing clams into which sediments from the larger ponds would settle.

OUTSIDE SOLAR POND NO. 10 — PM COUPLED WITHOUT FISH



GRAPH 7



The points measured on the graph are a result of daily measurements. The small circles below the dates indicate clear ○, *partly cloudy* ⊖, *and cloudy* ● *weather.*

GRAPH 8

Bill Stewart has given us another design idea. In all our populations of cultured tilapia, there has always been a size gradient in the fish. If the larger fish were removed, it might allow others to move into dominant growth positions. As the fish succeed one another, they could be graded and put into ponds of their weight class, presumably creating a similar growth differentiation. The solar-algae ponds would then be used as modular units in a growth ladder with the last pond containing the desired size of fish.

(see TABLE IV — next page)

Needless to say, the work described above could not have been completed by one person. I was very fortunate to have as assistants Carl Goldfischer and Chuck Hendricks who proved invaluable to the aquaculture program. Their dedication to daily routines and their inventiveness in finding solutions to problems as they arose were exceptional. Geoff Booth prepared devices for vegetative fish food cultivation.

TABLE IV - PRODUCTION DATA

System and Experiment	*Fish Production (grams)*	*Commercial Feed (grams)*	*Commercial Feed Conversion Ratio (dry feed/ wet fish)*	*Vegetative Feed Dry Weight (grams)*	*Total Feed Dry Weight (grams)*	*Total Feed Conversion Ratio (dry feed/ wet fish)*	*Time (Days)*
Dome (*Tilapia aurea* Monoculture)	3,191	2,810	0.88	4,159	6,969	2.18	158
Miniature Ark (Brown Bullhead Monoculture)	5,367	6,270	1.17				41
Miniature Ark (*T. aurea* Monoculture)	2,031						84
Solar-Algae Pond by Garden - Experiment 1 (*T. aurea* Monoculture)	998	1,242	1.24				137
Coupled Solar-Algae Pond (*T. aurea* Monoculture) Experiment 2	1,188	1,096	0.92				132
Solar-Algae Pond Inside Ark (*T. aurea* Monoculture) Experiment 3	3,874.5	3,607	0.93				127
Solar-Algae Pond (Polyculture *T. aurea* + 1 Mirror Carp) Experiment 4	3,093	2,553	0.82	454	3,007	1.0	92
Solar-Algae Pond A07 - Polyculture Experiment 5 Trial 1	869	1,067	1.23	740	1,807	2.1	119
Solar-Algae Pond A08 - Polyculture Experiment 5 Trial 2	1,051	1,067	1.0	769	1,831	1.7	119
Solar-Algae Ponds Linked A09-A010 Polyculture Experiment 5 - Trial 3	1,826	2,134	1.2	1,520	3,654	2.0	119
Solar-Algae Ponds Linked A011-A012 Polyculture Experiment 5 - Trial 4	2,027	2,134	1.1	1,306	3,440	1.2	119

1. Zweig, R. D. (1977) Bioshelters as Organisms. *The Journal of the New Alchemists (4)*, Woods Hole, MA.: pp. 107-113.
2. Zweig, R. D. (1977) The Saga of the Solar-Algae Ponds. *The Journal of the New Alchemists (4):* pp. 63-68.
3. McLarney, W. O., and J. H. Todd (1974) Walton Two: A Compleat Guide to Backyard Fish Farming. *The Journal of the New Alchemists (2):* pp. 79-117.
4. Syrett, P. J. (1962) Nitrogen Assimilation. *Physiology and Biochemistry of Algae.*, R. A. Lewin, Ed. Academic Press, New York: pp. 171-188.
5. Swingle, H. S. (1969) Biological means of increasing productivity in ponds. *In* T.V.R. Pillay (ed.), Proc. World Symp., Warm Water Pond Fish Culture, pp. 18-25. May 1966, Rome FAO Fish. Rep., 44(4): pp. 243-257.
6. Kilgen, R. H. (1969) Fishes as Biofilters for the improvement of pond water quality. Unpublished. Ph.D dissertation, Auburn Univ. 111 pp.
7. Sarig, S., and M. Marck (1974) Results of intensive and semi-intensive fish breeding techniques in Israel in 1971-1973. *Bamidgeh*, 28 (2), pp. 28-48.
8. Zweig, R. D. (1977) Part 1. The Miniature Ark. Three Experiments with Semi-enclosed Fish Culture Systems. *The Journal of the New Alchemists (4):* pp. 69-76.
9. Barnhart, E. A. (1976) Savonius Rotor. *The Journal of the New Alchemists (3):* pp. 27-29.
10. Lind, O. T. (1974) *Handbook of Common Methods in Limnology.* The C. V. Mosby Company, St. Louis, Mo. p. 63.
11. Doudoroff, P. (1957) Water Quality Requirements of Fishes and Effects of Toxic Substances. In *Physiology of Fishes, Vol. II.* Margaret E. Brown, ed. Academic Press, Inc., New York: pp. 403-430.
12. Wetzel, R. G. (1975) *Limnology.* W. B. Saunders Company, Philadelphia, Pa.: pp. 184-185, 197-198.
13. Moriarty, D. J. W. (1973) The physiology of digestion of blue-green algae in the cichlid Fish, *Tilapia nototica.* J. Zool., Lond., (171): pp. 25-39.
14. Spotte, S. H. (1970) Fish and Invertebrate Culture: *Water Management in Closed Systems.* John Wiley & Sons, Inc., New York: pp. 102-106.

The Birth and Maturity of an Aquatic Ecosystem

– Ron Zweig

For over two years we have been subjecting our aquatic systems to intensive evaluation in the attempt to discover those parameters critical to productivity. The impact of such environmental factors as solar energy and temperature are monitored to help us learn more about the inherent, internal relationships within physically defined microecological systems. Findings are indicating certain basic ecological phenomena as well as some of the limits of productivity to be expected. Recent research has helped us understand several biological phenomena within the polyculture pool, particularly photosynthesis and its interrelationship with sunlight. Thresholds of light necessary to drive the system were evaluated.[1]

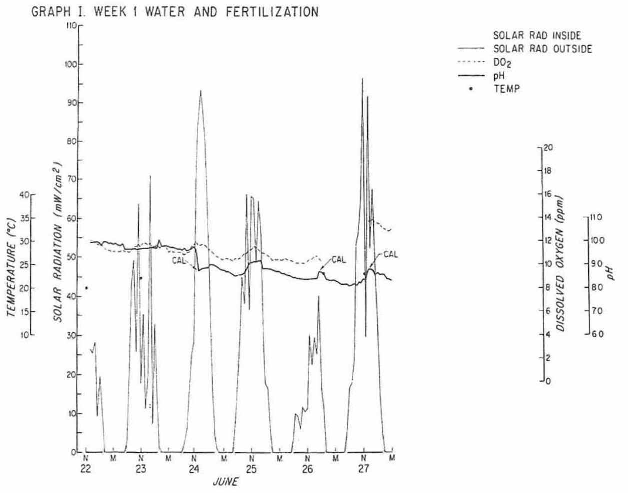
In 1977 an experiment was designed using a solar-algae pond located inside the Cape Cod Ark[2]. The purpose of the investigation was to determine the phenomena necessary to develop an ecological model of the ponds. On June 22, 1977, the pond was filled with tap or town water, which is almost free of organic material. Beyond residual sediments from a previous experiment, the water was free of life-supporting material. Within a week, male urine was added to the trace plankton cells in the pond to encourage a phytoplankton bloom. The impact of the addition of nutrients upon the water chemistry was monitored. This was the first stage in developing an ecosystem within the pond. As diurnal rhythms became established, the relationship between solar energy entering the system and the photosynthetic behavior of the algae became apparent. The water was a major component of the phytoplankton-based ecosystem and integral to the behavior of the algal cells. The water chemistry is a reflection of the combined metabolic activity of the organisms present in the pond.

The second step, which took place one week after the pool was fertilized, was the addition of a population of newly hatched *Tilapia aurea.* The only other input into the system was a daily minimal feeding of Purina Trout Chow. (R) The investigation continued until the first week of December. It was monitored continuously throughout that period.

Biological Monitoring

Instrumentation:

The solar-algae pond in this study is in position AI9 inside the Cape Cod Ark (see Diagram 1)[3], on the upper level of the aquaculture section, beneath the insulated northern roof. A Chemtrix Model 40E pH meter was used to measure the hydrogen ion concentration of the water. A Yellow Springs Instruments Model 57 Dissolved Oxygen Meter was used to measure the dissolved oxygen (DO_2) in parts per million (ppm). Tem-



GRAPH I. This figure represents the first week of monitoring Solar-Algae Pond AI9 inside the Cape Cod Ark. Dissolved oxygen is in parts per million and solar radiation in milliwatts/cm.^{2} The pond temperature was measured once daily while the others were measured continuously. The chart recorder ran somewhat erratically, creating the discrepancy between real time and expected sunlight intensities.

peratures (°C) were taken. The solar radiation striking the upper portion of the pond as well as ambient outside levels were measured with Agromet-Lintronic Dome Solarimeters in milliwatts per square centimeter (ms/cm^2). All the parameters were linked to an Esterline Angus twenty-four channel multipoint chart recorder – Model E 1124E – and were recorded constantly throughout the experiment with the exception of temperature which was measured once daily in the afternoon. There were deviations in the accuracy of the recorded data, resulting from the pH and DO_2 meters requiring daily calibrations, battery checks or recharging. The calibration of the pH meter was adjusted so that pH 7.0 read pH 10.0 on the meter to allow compatibility with the chart recorder which reads only positive polarity in voltages. If the instrument had read levels below 7.0, a negative polarity would have resulted that would have read at 0.0 millivolts on the chart recorder. At times, the pH of the system went above 11.0, the limit of the meter as calibrated, and in some instances the maximum was not determined. The recorder was set to move the chart paper at one inch per hour. On occasion it ran somewhat erratically. All recordings were measured in sequence. Thus, each factor as measured was relative to the others at any moment in time, creating a direct relationship between them. A total of six weeks was transcribed. For the first five weeks the time increments were related directly to Eastern Daylight Time. The last week was on Eastern Standard Time. The first three segments transcribed are from the first twenty consecutive days of the experiment. The last three are taken from separate weeks throughout the investigation.

The Generation of an Aquatic Ecosystem

Week 1. Tap Water and Fertilization:

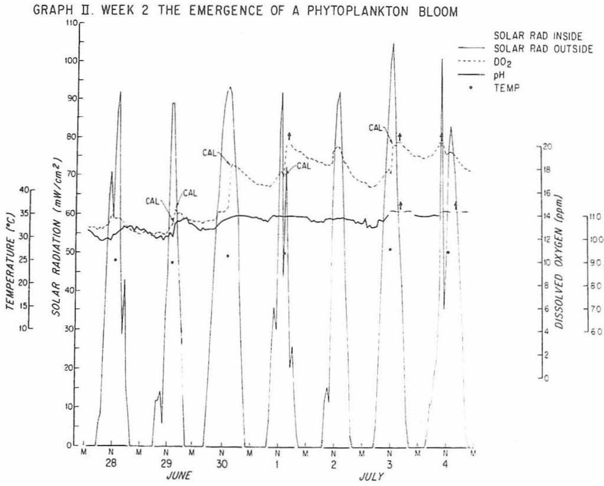
The first six days of monitoring are described in Graph 1. Clean tap water was put into the pond at 20°C. Monitoring began at noon on June 22, 1977. For the first two days, the recorded pH and DO_2 levels were fairly steady. The pH showed a fluctuation of a half unit, the oxygen a fluctuation of nearly one part per million (ppm). On June 24, distinctive diurnal rhythms became evident, probably the result of residual organic matter in the pond that provided a nutrient base for the small populations of phytoplankton and bacterial cells resident in the ponds at the outset of the experiment. On the morning of June 27, an aliquot of human male urine was mixed into the water column. (See page 98). This was done in many of the solar-algae ponds. There was no inoculation of algae. Rich blooms resulted, predominantly chloroccocales, *Golenkinia* sp. and occasionally *Scenedesmus* sp. In this case, it was the *Golenkinia.*

From the graph for Week 2, it appears that, as the water warmed from 20° to 23°C, the DO_2 concentration gradually decreased. The higher the water temperature, the lower the concentration of DO_2[4]. Diffusion seems to have a direct effect on the balance of gases in the water. The pH levels dropped, possibly as a result of bacterial activity which would have utilized residual organic matter in the water and released organic acids and carbon dioxide. Relatively small quantities of these compounds could induce such changes as there was no component to buffer the pH. The significance of this became apparent subsequently. On June 24, the oxygen level increased, perhaps due to the respiratory products that were becoming available to the small algal population. A series of diurnal fluctuations began and continued for the next two days.

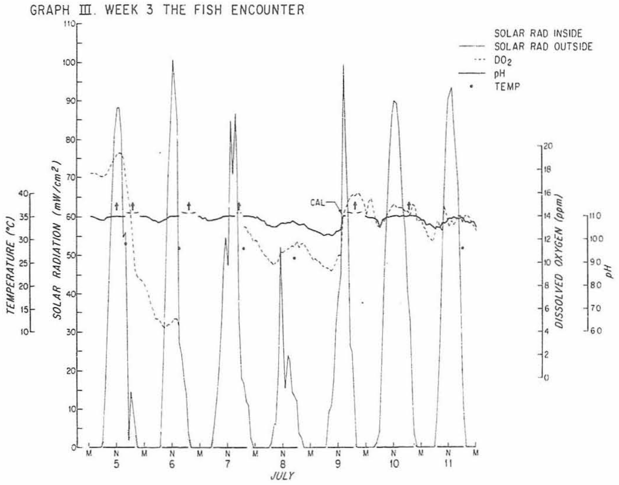
Following fertilization, because of the nutrients being supplied to the phytoplankton, a radical increase in the DO_2 concentrations was measured. The immediate impact of these nutrients cannot be exactly determined, as the DO_2 meter was being recharged when the nutrients were added to the pond, delaying measurement. As the previous day had been cloudy, a build-up of respiratory products or nutrients necessary for the photosynthesis had occurred. The data contained in Graph II show the importance of the fertilization of this pond.

Week 2. The Emergence of a Phytoplankton Bloom:

Graph II represents the week following fertilization and is a direct continuation of Graph I. For the first two days of this week, DO_2 levels remained similar to those recorded directly after fertilization, which likely indicates that the added nutrients were partially utilized by the existing phytoplankton population without significantly increasing its numbers.



GRAPH II. This figure represents the second week of monitoring of Solar-Algae Pond AI9. The measured factors are the same as in Graph I.



GRAPH III. This figure represents the second week of monitoring AI9.

Every day of this week was very sunny. There was little cloud cover. A radical change in the oxygen levels in the pond did not occur until June 30, indicating a three day delay before a substantial phytoplankton bloom developed. During the day, a significant increase in DO_2 and pH levels was evident. There was a corresponding decrease at night when algal cells did not undergo photosynthesis but continued to respire.

With the development of the phytoplankton bloom *(Golenkinia)* on June 30, the system developed a more dramatic chemical behavior pattern, resulting from the interaction of the algal cells with the sunlight. A period of active productivity during the day was followed by a passive phase at night, during which the phytoplankton survived on stored DO_2. A 24-hour day could be compared to the yearly seasonal cycle, the periods of sunlight being analogous to the productive summer months and the nights to winter. In a broad sense, the varying daylengths throughout the year could be compared to the differing seasonal lengths at different latitudes. Productivity would be limited to the length of time and intensity of available sunlight. Dawn would correspond to spring and dusk to autumn.

Week 3. The Fish Encounter:

On July 5, 350 *Tilapia aurea* weighing 56 grams were put into the solar-algae pond. At the time of their introduction, both pH and DO_2 recordings were suspect. For the week described in Graph III, the recorded pH reached the calibrated upper limit of 11.0 on five of the transcribed days but it was likely higher. DO_2 readings for the first three days are somewhat dubious. On July 5, after the fish were put into the pond, the DO_2 concentrations dropped radically. As the fish were in a highly perturbed state after handling, respiration would have been higher than normal and therefore could have caused the drop in DO_2. It is also possible that the batteries of the submersible stirrer were low. Further understanding of the post-perturbation respiratory responses of the fish is necessary.

The last four days of this week indicate the impact of the fish on the system. Prior to their introduction, from June 30 to July 5, it was sunny and DO_2 levels were between 16.0 and 20.0 ppm. Similarly, July 9 through 11 was sunny. DO_2 levels were between 11.8 and 15.8 ppm, an overall drop in the concentrations. The range of the fluctuations is approximately the same; 4.0 ppm indicating that the fish contributed to the shift, which could also have been affected by greater bacterial density and activity.

During the week beginning July 6, the fish were fed a total of 29.1 grams of trout chow. As a result of daily feedings, fish wastes increased, supplying more nutrients to the pond. The precise impact of the feed on the water chemistry is complex, involving several factors:

1) additional nutrients available to the algae, allowing for increased photosynthetic activity;
2) increased nutrients available to bacteria stimulating respiration and increasing the population; and
3) greater fish mass triggering increased respiration.

Temperature fluctuations would have had an impact of less than 1.0 ppm.[4]

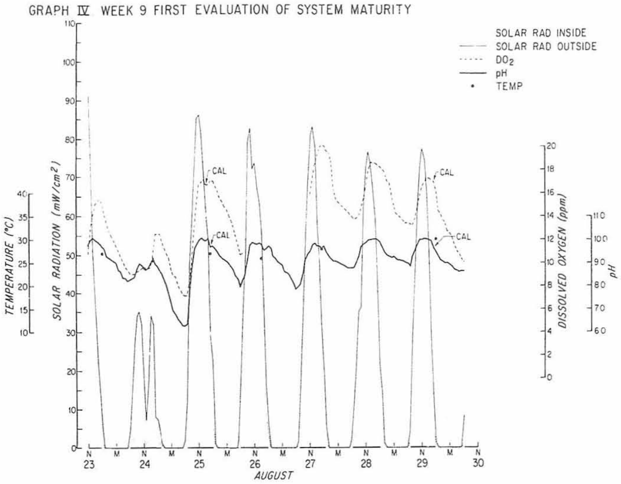
The hourly fluctuations in the DO_2 during the last three days are difficult to explain as other than mechanical error. The pH levels during these days, particularly the last two days, show a steady decrease. The small amount of organic matter that was building up in the pond would have tended to drive down the pH through bacterial metabolism which produces organic acids as by-products. As the ponds have little buffering capacity, such compounds could be significant. Also, pH levels are closely related to the photosynthetic activity of the algae. As carbon dioxide and bicarbonates are utilized, the system becomes more alkaline.[5]

Week 9. First Evaluation of System Maturity:

Over the next six-week period the water chemistry in the pond gradually became more active as illustrated in Graph IV. Diurnal fluctuations became extreme and definitive. The effect of solar energy impinging upon the plant life in the pond is very clear. The rise and fall of pH reflects similar changes in concentrations of carbon dioxide and bicarbonate. Sensitivity to sunlight was observed. At mid-day, on August 24, a cloud cover reduced the light penetrating the pond. The change was reflected in the recorded levels of DO_2 and pH, which had been rising. A definite drop in the curves showed that productivity had been reduced and that the respiring organisms were consuming more oxygen than was being produced. Then, as the cloud cover dissipated later in the day, a steady increase in values was measured.

There are several similarities in the activity of above-ground ponds such as this and that of subsurface systems like the dome pond. Maximum levels of solar energy entering both systems do not directly correspond to maximum levels of oxygen dissolved in the water. A lag occurs after which the concentrations reflect maximum light intensities. The rate of photosynthesis corresponds closely to the amount of energy available at a given moment.

Graph IV records the same week from the previous year's research describing the dome pool.[1] Although they vary in physical factors, the overall response of the dome and solar-algae ponds in terms of diurnal rhythms is quite similar.



GRAPH IV. This figure represents the third week of monitoring AI9.

One response to fluctuations in light evident in both is the hour or two lag time by which the rise and fall in pH levels precedes increasing and decreasing DO_2 concentrations. This indicates that significant amounts of carbon dioxide and other compounds that induce low pH are being used in algal metabolism and thereby are being removed from the system. What is being measured, after sunrise, for instance, is a decrease in dissolved oxygen depletion rates as low pH-inducing molecules are removed. Once photosynthetic activity is sufficient to raise the DO_2 concentration beyond that necessary for equilibrium with respiratory activity, after a lag period, a measured rise in concentration occurs following the rise in pH. The inverse of this process occurs toward the end of the daylight period when a drop in pH precedes a fall in DO_2 concentrations.

By the end of the ninth week of the experiment, a total of 274 grams of commercial feed had been fed to the fish. This amounted to the total input of nutrients beyond initial fertilization and whatever atmospheric gases that may have diffused into the pond through the surface. No sediments were removed.

The fact that the pond is inside the Ark is determinative. On the relatively clear days of Week 9, the intensity of the light striking the pond was greater than that recorded during the previous weeks closer to the summer solstice. Although the outside light intensity was less, the closer angle of the sun to the horizon allowed more light to come in under the roof which in early summer had shaded the pond. Although the light intensity may decrease with the shorter day in winter, the overall quantity of light received by the solar algae pond in this location may have been close to equal to that of the summer.

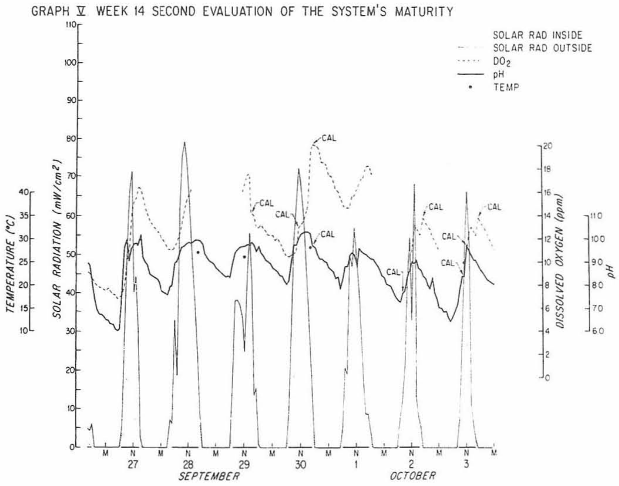
Week 14. Second Evaluation of the System's Maturity:

The data collected during this week and plotted in Graph V are similar to those of Week 9. Fluctuations in water chemistry were nearly the same. The light intensity entering the pond was somewhat less. Feeding was continued daily with an addition of 163 grams of commercial feed making a total of 437 grams at the end of the week.

The behavior of the system was relatively stable through to this week. In October, a series of cloudy days reduced the overall productivity and threatened the system. During this time, the pH was recorded at 6.1 and the DO_2 at 1.0 ppm; a stressful condition for tilapia, as they originate in lakes which are predominantly alkaline. Low oxygen levels stress both respiration and metabolism.

Week 22. The Last Evaluation of this System:

The data transcribed from this week in Graph VI illustrate the dramatic effect of low light on the aquatic

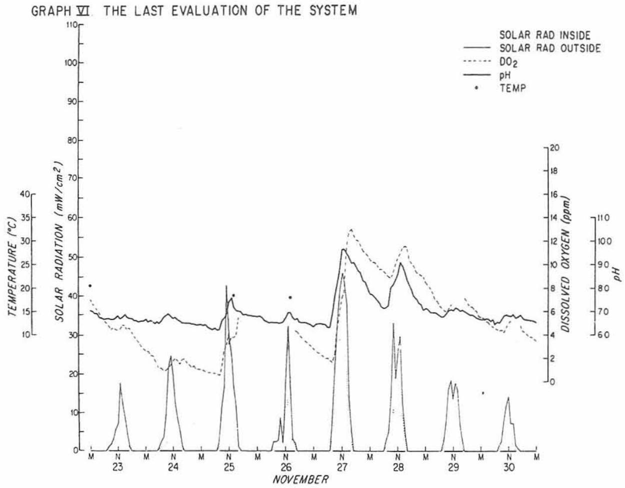


GRAPH V. This figure represents the ninth week of monitoring A19.

ecosystem. The combination of low light level and a build up of detritus on the bottom reduced diurnal curves. Compared to previous graphs, the fluctuations of November 27 and 28 are less, but sufficient energy to drive the system is still available. The lower oxygen levels are still well within safe limits for the fish. The low pH may be more of a problem. For four of the last eight days transcribed, levels are below 7.0. The exact effect of this on the fish growth requires further experimentation.

Summary

On December 5, 1977, a total of 335 tilapia were taken from the pond. They weighed 861 grams, a net increase of 805 grams. They were fed a total of 748 grams of commercial feed, bringing the dry feed to wet fish conversion ratio to 0.93. It should be remembered that this was not an experiment in intensive production. Growth was maintained at a minimal level. The goal was to determine the impact of the various phenomena qualitatively.



GRAPH VI. This figure represents the last week of data transcribed from this investigation of A19.

Variation in day length and sunlight intensities were shown to have significant impact upon evolved eutrophic condition, indicating that latitude is significant in designing light-based food-production systems.

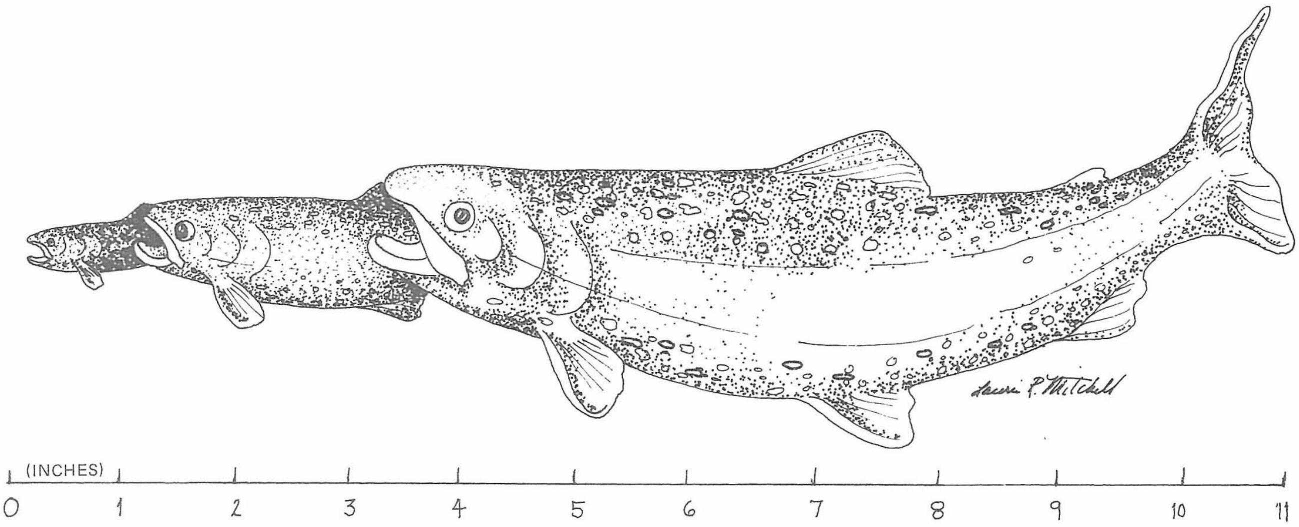
Intensive computer study is not the only method by which we are studying the various units of our aquaculture. While we use instruments to record properties that are not readily discernible to the observer, we are, at the same time, developing a parallel set of human sensory criteria for pond management. Much as a parent can tell at a glance the general health of a child or a gardener his or her plants, we want to learn the sensory stimuli to observe the metabolism of the systems. As for the solar-algae ponds, we think that their small, modular nature makes them easily adapted to placing in a house, apartment, patio and/or rooftop. They could be placed near a window with a southern exposure (in the northern hemisphere), possibly with planting boxes for vegetables below the window that could be irrigated with the sediment-rich water from the bottom of the pond. We intend to continue experimenting with and monitoring our aquaculture units both to maximize productivity and to better understand their aquatic ecology. We look forward to replication, adaptation and feedback on our work.

* * * * * * * * * * *

I had considerable assistance in the collection and analysis of the data used in this article. Carl Goldfischer and Manuel Mir helped in the daily monitoring of the pond. Meredith Olson assisted in transcribing the recorded information.

BIBLIOGRAPHY

1. Zweig, R. D. 1977. "Bioshelters as Organisms." *The Journal of the New Alchemists (4).* Woods Hole, MA 02543 , pp. 107-113.
2. Zweig, R. D. 1977. "The Saga of the Solar-Algae Ponds." *The Journal of the New Alchemists (4).* Woods Hole, MA 02543, pp. 63-68.
3. Zweig, R. D. 1977. "Investigations of Semi-Closed Aquatic Ecosystems." *The Journal of the New Alchemists (5).* Woods Hole, MA 02543, p. 93
4. Lind, O. T. 1974. *Handbook of Common Methods of Limnology.* The C. V. Mosby Company, Saint Louis, p. 63.
5. Wetzel, R. G. 1975. *Limnology.* W. B. Saunders Company, Philadelphia, pp. 184-185.



The Second Wave:

The Application of New Alchemy Aquaculture Techniques to a Remote, Small-scale Trout Farm

— Meredith Olson

Research in fish culture at New Alchemy has been directed toward developing workable techniques for small-scale fish farmers or for those interested in backyard aquaculture. The work has been primarily with warm water species. Most of the literature on the culture of cold water species is aimed at large-scale application based, for the most part, on techniques used in state and federal trout and salmon hatcheries. After reading some of the available information about trout culture, one begins to wonder if trout culture on a small scale is possible.

Last year I took part in a project at Holden Village, an educational and religious retreat center in the Cascade Mountains of northern Washington, where there was an interest in developing fish culture. Since the water supply there comes primarily from streams fed year-round by the runoff from glaciers and snow fields, we began to explore the possibilities of a small-scale trout farm. With encouragement from Lauren Donaldson at the College of Fisheries of the University of Washington and from New Alchemy's Bill McLarney that trout culture need be neither technology-intensive nor large scale, we decided on an experimental project. The objective was to explore the feasibility of trout culture within the context of the community life of the Village at Holden, not only in order to produce some of our own food, but also to provide an educational model of a small-scale, cold water fish farm for the 5,000 people that come through the area each summer.

Holden is unique for this type of work in several ways. It is located in the wilderness of the Wenatchee National Forest. The Village is accessible only by a 35-mile hiking trail, or by a 40-mile boat trip up Lake Chelan, followed by a 12-mile drive 2,000 feet up into the mountains. During the winter, due to heavy snowfall — there had been 250 inches by January, 1978 — this road is closed to all but tracked vehicles. In view of the expense in time, energy and money of bringing in supplies, one can see how enticing was the idea of producing part of the Village's food supply.

Attempts at agricultural production in the area have met with limited success due, in part, to the short growing season, as well as to an abundance of predators including deer and bears. An aquacultural project was likewise not without limitations. The fish ponds would be fed by icy streams with temperatures well below the lower limit of the range recommended for economic trout culture, where 11-15°C (52-58°F) are optimum. In addition, the Village, now owned by the Lutheran Church, was originally the site of a large copper and gold mining operation owned by the Howe Sound Mining Company. The mine, in operation from 1937 through 1957, left the Village a legacy of an adjacent eighty acres of copper mine tailings. Air and water contamination with these very fine-grained mine wastes has resulted in the depletion of fish and invertebrate populations in areas downstream from the Village. However, the good fishing in the lakes and streams above the tailings encouraged us to go ahead with a small feasibility study.

A final consideration before we began the work was that of competence. The Village operates primarily on a volunteer staff and there was not a cold water fish culture expert available to direct the project. Somewhat hesitatingly, I accepted the responsibility of setting it up, wondering all the while whether my experience in aquaculture at graduate school in Puerto Rico would have any application to this rather distant relative of warm-water pond fish culture. I consulted with people at the College of Fisheries of the University of Washington and the State Game Department, as well as several independent consultants, some of whom were very interested and supportive and had important inputs on the work. The biggest boon to the project overall was the help of Dave Kuhlman, a recent graduate of the University of Washington's College of Fisheries, who had had experience with trout and was eager to learn more about aquaculture. Another stroke of fortune came in contacting Jim Ellis, an aquaculture consultant associated with the Lummi project in Bellingham, Washington, who made several trips to look over the site. His many suggestions and detailed letters on how to proceed, which included the initial plans for the pond construction, were a major impetus. Bill McLarney suggested we try solar heating as well as some innovative systems of feeding and gave me much-needed encouragement on the need for and the value of small projects such as ours. And, the support of the many dear people at Holden, including the mechanic, electricians, carpenter, high school and life-style students, cooks, administrators and pastors, who helped in all stages of the work from the initial pond digging to the final serving of the fish, is what really made this project possible.

Pond location and design:

The first step was to find a suitable location for the ponds. In addition to the primary concerns of the quality and quantity of water supply, we wanted to find a natural site so that extensive construction would not be necessary. Easy access from the Village was another prerequisite. Using several small Hach and La Motte water quality test kits, we measured the temperature, dissolved oxygen (DO), pH and copper concentration in nearby creeks. Since minute amounts of copper have been shown to be toxic to trout in soft water in concentrations as low as 0.05 parts per million (ppm), copper contamination was our most obvious fear.

We found a location which seemed to meet most of our requirements in a small, rock-lined stream at the outflow of our hydroelectric plant which flows through a sauna/recreational area for several hundred feet before dropping into Railroad Creek. The hydro plant receives water through an underground pipe from a dam 700 feet above. The water is diverted from Copper Creek (a slightly suspicious name) well above the main mine tailing area. Except for its coldness, other parameters for water quality seemed satisfactory and the water appeared free of copper contamination. Since this stream was already receiving a regulated flow at 7 to 10 cubic feet per second (cfs) during the summer months, we would not have to worry about flooding, especially during spring melting. Most streams swell considerably at that time and often carry trees, roots, leaves and other detritus, which can cause problems to the fish culturist.

We knew that water temperature would be a major limiting factor at this location but we were planning to work out a heating system for the pond. Other plans for the area included the construction of a water wheel and several solar collecting panels. We were also worried about the possibility of toxic substances leaching from the tailing pile into the pond water, but we planned to have rock-lined ponds and to allow several weeks after finishing construction before stocking the fish, thereby hopefully leaching out potentially harmful substances.

Pond construction began as soon as the snow melted in the spring of 1977. The ponds were relatively easy to build as we had only to widen and deepen the stream slightly and to install a screen which would allow water to flow through but would contain the fish. Preliminary excavation was done with a backhoe. Learning to use this piece of machinery from Mike Beaver, the Holden mechanic, turned out to be one of the more exciting parts of the pond preparation. We used hand tools on the banks and lined the pond bottom and sides with rocks. Adjacent areas were planted with some trees and seeded with grass.

When it is necessary to overwinter some of the fish two ponds are needed. A separate pond is then available to stock the young for the next year's crop. The design of our pond area is shown in Figure 1. Each pond was about 60' x 12' x 3' and could support over 2,000 pounds of trout. The screens were built of a frame of 2 x 4's, inlaid with vertical wooden slats, ½-inch wide spaced ½-inch apart and nailed in at each end. One horizontal 2 x 4 was set in across the back of the screen to prevent the bars from bending from the pressure of the water. The vertical slats allowed needles, leaves and other detrital material to pass through the ponds without clogging the screens and causing a backup of water. We needed to clean off the screens with a rake once or twice a day.

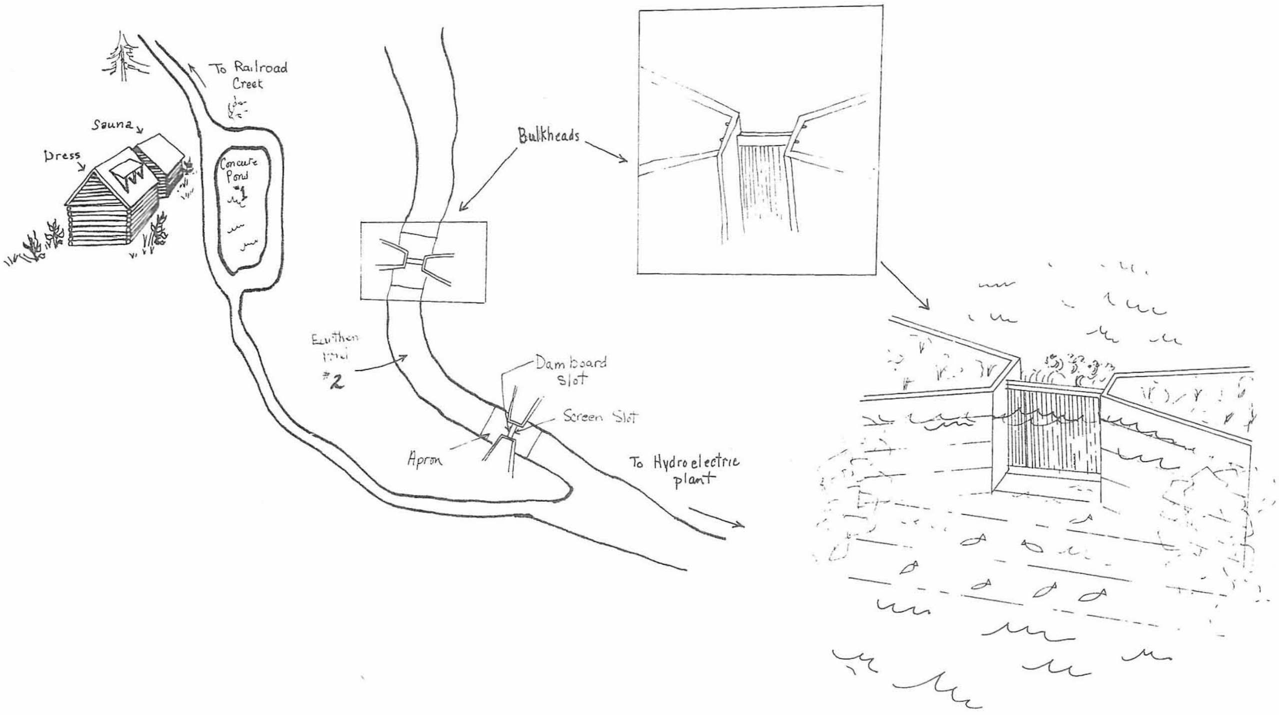


Fig. 1

The screens were supported between two wooden, earth-filled bulkheads that extended back into the bank. In addition to the slot for the screen, there was an additional one for dam boards which regulated the depth of the pond. To prevent water from undercutting the screen and bulkheads, they were supported by an underlying apron, built of 2 x 12's, which also contained slots for the screen and dam boards. The apron was 12 feet wide, the full width of the pond, and 12 feet long. A vertical board 12 inches deep was attached at both ends of the apron and packed with small rocks and gravel to prevent water from washing in underneath it.

The bulkheads were designed to be eight to ten inches above the high water mark. They were spaced five feet apart, but the water still backed up somewhat when the screen was put in. This necessitated building up the banks of the pond with sand and pea-sized gravel upstream from the first bulkhead to contain the higher water level.

After about a month's work on pond construction, another site became available to us. It was a concrete pond (15' x 30' x 3') that had been built as a sauna plunge. It was fed by a four-inch pipe which ran from near the tailrace of the hydro to a 750-foot-long rock-lined channel that spilled down into the pond. The water in this pond could become considerably warmer than that in the main flow which ran through the earth ponds because of the reduced water flow and the shallow inlet channel. As water temperatures ranged from 5° to 10°C (41° to 50°F) in Copper Creek during the summer, we wanted to take advantage of the higher temperatures in this pond which, on sunny days, were as high as 15°C (59°F). Promising lots of trout dinners in the fall, we were able to gain general agreement to use the plunge as a trout culture pond for the summer, while sauna-goers were able to plunge in nearby Railroad Creek. Thus, we fortuitously found ourselves with the recommended two ponds.

Stocking and sampling of fish:

Rainbow trout (*Salmo gairdneri*) seemed a logical choice of fish. Of the cold water species, they are best

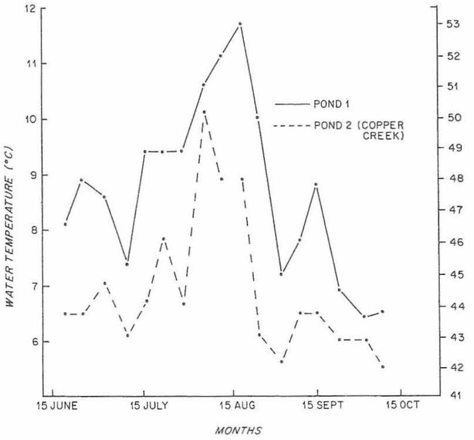


Fig. 2

suited to cultured conditions and are available at many of the hatcheries around the State. The first summer we decided to stock 4,000 fish, a relatively small number considering our flow rates and pond size. However, we wanted to minimize the investment until we found out if and how well the fish would survive. The people at the Chelan Falls State Fish Hatchery provided us with information about the rearing program, and Clair Sackenreuter, the Director of the Hatchery, assisted us in acquiring the fish. On June 9, 1977, the fish were brought up-lake on the barge for stocking into the ponds:

Fish Stocked	Pond 1 (concrete)	Pond 2 (earthen)
Number of fish	4,060	11
Mean individual wt.	16 g (29/lb.)	650 g (1-2 lb.)
Mean length	10 cm (4")	30 cm (12")
Age	5 months	27 months

On July 1 we transferred 45 of the largest fish from the concrete pond (or Pond 1) to the earthen pond (or Pond 2) to see the effects of the latter on the smaller fish. We are not sure whether these fish squeezed through the ½ inch-screen or hid in the rock-lined pond bottom, but we did not see them again. On July 30, we transferred an additional 50 fish, this time enclosed in a cage, from Pond 1 to Pond 2. In mid-July we also stocked Pond 2 with an additional six large rainbows which we received from the state hatchery.

Because of higher water temperatures and the ease of sampling and cleaning the concrete pond, the main experiment with growth and feeding was conducted there. We tried to maximize solar absorption in the inlet channel by lining it with black polyethylene. On sunny days, the temperature rose as much as 3°F in the 75-foot stream.

The fish were fed both natural food organisms and commercial feed. We installed a Will-O'-the-Wisp (R) bug light on a floating raft about three feet above the water in Pond 1 to capture insects for the fish during the night. Later in the summer, we installed another bug light with an attached mesh collecting bag inside a garbage collection area from which we periodically removed the insects and brought them to the fish. Dave began a worm culture project by stocking two large wooden worm boxes, one with several hundred breeders and the other with about 1,000 smaller worms. Since we were just starting worm culture, there was not time for enough growth to allow periodic cropping. Instead, the fish were fed a commercial pelleted feed three times daily at a rate recommended by the manufacturer, based on the mean size of the fish and the water temperature.

The concrete pond was cleaned about once a week using two different methods. Early in the summer, we opened a drain at one end of the fish pond and swept the wastes off the edges and bottom down to the area of the drain. Later, when we were seeding grass nearby, we scoured the pond bottom with a hose and pumped the wastes over to a sprinkler for use as fertilizer.

To estimate the mean individual weights of the fish and to determine the growth rates, we sampled the ponds once a week. Using a small seine net with a ¾-inch stretch mesh, we easily netted over half of the population, from which we counted and weighed several dip nets full, weighing from six to ten pounds. By determining the average weight, we could extrapolate the total weight and the food conversion efficiencies based on the weight of feed added to the weight of fish flesh gained.

We began to harvest the fish by the end of September. The minimum harvestable size was set at seven inches. After seining the pond, we selected the largest fish visually. They were measured into groups based on length in inches, then counted and weighed by size class. After cleaning, which consisted of evisceration and removal of gills, they were re-weighed to determine dress-out percentage (cleaned weight/live weight x 100). As a cost evaluation was included in the study, this was done to find the weight of the salable product.

Results and Discussion:

Although the design of the screens and bulkheads in the earthen pond worked very well, results were conflicting. Within six weeks from the initial stocking, all the larger rainbow trout were dead. Since most of them died within the first several weeks, we assumed the mortalities to be due to stress at the time of stocking. At the second stocking, care was taken to minimize stress both during the trip up-lake and during the temperature acclimation period. However, only two of the six fish survived through the summer.

Both earthen and concrete ponds received water from the same source. Since mortalities in the concrete pond were very low, we tried to determine the causes of the high mortalities in the earthen pond. Differences between the two included mean daily water temperature, flow rate, pond substrate and the age of the fish stocked. Water temperatures were consistently higher in the concrete pond than in the main flow of the earthen pond (see Figure 2). There may have been a trace amount of a toxic chemical, too small to measure, which leached into the earthen pond, but did not penetrate the concrete pond.

To determine whether the size of the fish affected survival, we stocked some fingerlings in the earthen pond. Since the first group disappeared, we had only the second group of fifty caged fish on which to base observations.

Although not all these fish exhibited normal feeding behavior and there was about 10% mortality within two months, most of the fish appeared to adapt to the earthen pond within several weeks. Unfortunately, the experiment was abruptly terminated in mid-November when a bear dipped a paw into the cage for a pre-hibernation snack. Therefore, we still have to conduct further experiments to determine the suitability of this pond for trout.

Results in the concrete pond were more heartening. A summary of the growth and production data based on the samplings and partial harvest in Pond 1 through the fall of 1977 is shown in Table 1. The survival rate, 98%, of these fish was high. Based on the last sampling, the cumulative food conversion efficiency for the fish in this pond was 1.65 (dry weight feed added/wet weight fish flesh gained). During a period of four or five months, over one-third of the four-inch fingerlings reached marketable size. The dress-out percentages of these fish were 68% for the seven-inch fish, 75% for the eight-inch fish and 86% for the nine-inch fish.

Although it is premature to draw definitive conclusions as to the economic feasibility of the project until the final harvest, we can venture some speculations based on the last sampling in the fall and the fish harvested at that time. By October 10, we had harvested 1,013 trout, which represented 26% of the population by number, but 33% of the standing crop by weight. Therefore, to estimate the cost of production per pound, we can assume that these fish consumed approximately one-third of the feed that had been added to the pond by this time (82.5 kg). Their total harvested weight was 83.2 kg, with a dress-out percentage of 78%, or 64.8 kg. Based on feed costs of $.18/lb., or $.40/kg., the production cost of these fish is approximately $.63/kg ($.27/lb.), based on feed and transport costs. If the price of the fingerlings (about $.10 each) is added, this increases to $2.19/kg ($1.00/lb.) which can be compared to $1.89/lb., the price for fresh rainbow trout in the Seattle fish market.

The growth curve of the fish in Pond 1, based on the mean weights at samplings, is shown in Figure 3. As one would expect, growth begins to accelerate around the end of July when water temperatures increased substantially. It appears obvious that longer periods of warmer temperatures would allow more fish to reach harvestable size within one season.

An additional factor that would have allowed for increased growth would have been access to more ponds for grading the fish, a procedure recommended for trout. The wide variation in size within the population is shown in Figure 3, where the mean weights of the harvested fish are over one-and-a-half times greater than the mean weight of the population as a whole. Since we were unable to grade the fish, we undoubtedly hindered growth in all size classes by not feeding enough to the larger ones, and forcing unfair competition on the smaller ones.

Although we began to work on the culture of live foods, for the first summer we were almost totally dependent on commercial feed. Worms were harvested several times at the end of the summer but did not contribute significantly to the diet of the fish. Although the insects that the fish received from the

Table 1.

Stocking: June 9, 1977	
No. fish stocked	4,055
Mean individual wt.	16 g (29/lb.)
Total wt.	63.6 kg
Feeding and Sampling (based on samplings through September, 1977):	
Mean individual wt.	51 g (9/lb.)
Total wt.	195.9 kg
Total feed added	218.5 kg
Total weight gain	132.2 kg
Cumulative food conversion	1.65
No. mortalities	77 (plus 99 fish removed to Pond 2)
Per cent survival	98%
Harvesting (through November, 1977):	
No. fish harvested	1,529
Mean individual wt.	82 g (6/lb.)
Total wt.	125.7 kg
Cleaned wt.	89.3 kg
Dress-out percentage	71%
Per cent harvested	39%

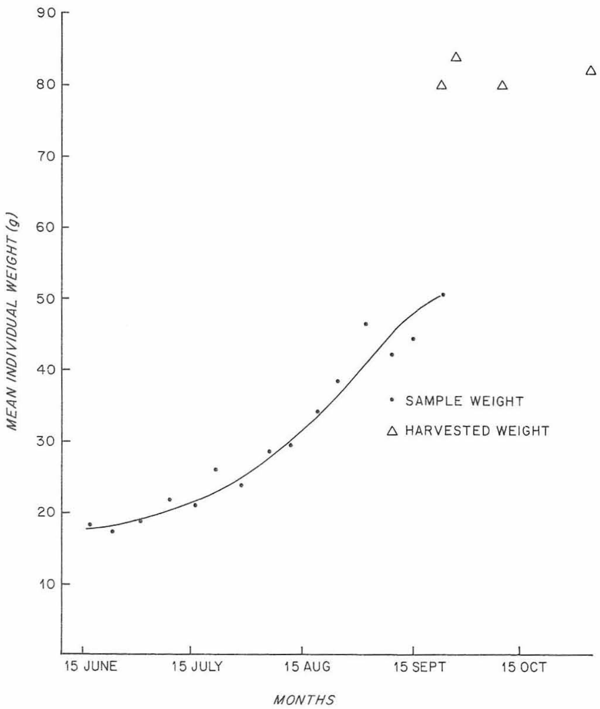


Fig. 3

bug light were not weighed, night temperatures were warm enough for insects to be in abundance only during several of the hottest weeks in mid-summer. The light near the enclosed garbage collection area provided insects for longer in the season than the outdoor light, but still not in sufficient quantities to allow for a reduction in the commercial feed.

Approximately two-thirds of the fish are being held over winter and hopefully will reach harvestable size during the next year. Although growth and production appear encouraging to this point, several other factors are important in determining the feasibility of continuing this project. If, for some reason, the fish are unable to survive the winter in the pond, it would not be worthwhile to continue the project as it was conducted this year with only one-third of the fish reaching harvestable size within a season.

There are several alternatives to overwintering: 1) to stock larger fingerlings at the beginning of the summer; 2) to develop further heating and/or recirculating facilities that would allow increased feeding and growth rates; and 3) to move the project to another location where it would be possible to utilize a creek with warmer water. As stocking larger fingerlings would increase the cost of the project considerably, we probably will not turn to this option. Heating the water by passing it through a series of black pipes or hoses or by constructing a small, shallow holding pond which traps solar heat is a possibility. Covering the pond would reduce cooling through evaporation. By recirculating and aerating the water during the evenings, the drastic overnight reduction in temperatures, which was as much as 11°C, or 20°F, could be minimized. New locations are becoming available to us ten miles downstream on Railroad Creek and on Lake Chelan, where year-round temperatures are warmer. We are exploring the possibilities of using these.

An important part of any feasibility study is consumer acceptance. A common complaint of hatchery-reared trout is that the flavor is bland and the flesh soft in comparison with their wild counterpart. Prior to the large-scale harvest, a taste test was conducted in which seventy-four guests completed a multiple choice questionnaire evaluating the flavor of the fish. 59% of the people rated the overall taste of the fish as excellent and an additional 34% rated it as good. 90% felt that the fish was equal to or better than the wild trout that they had tasted. We felt that the cold water temperatures were probably an asset with regard to the flavor and to the consistency of the fish.

Overall, we felt that the project was very successful, particularly considering that mean water temperatures were within the range considered necessary for economically feasible trout culture for only about two weeks. At the time of this writing the fish are still active and feeding and growth appears to be good. There have been two mid-winter harvests, removing an additional 400 fish, with a total weight of 47.5 kg, and a mean individual weight of 118 g. We are looking forward to expanding the project next summer and planning to emphasize the development of natural food sources, warmer water to encourage increased growth rates, exploring new species, and the use of polyculture techniques. Suggestions and visitors are welcomed. Further information about the Village can be obtained by writing to Holden Village, Chelan, Washington 98816.

REFERENCES

Bardach, J. E., J. H. Ryther and W. O. McLarney. 1972. *Aquaculture: The Farming and Husbandry of Marine and Freshwater Organisms.* Wiley-Interscience, New York. 868 pp.

Davis, H. S. 1973. *Culture and Diseases of Game Fishes.* U. of California Press, Berkeley. 332 pp.

Hines, N. O. 1976. *Fish of Rare Breeding: Salmon and Trout of the Donaldson Strains.* Smithsonian Institution Press, Washington, D. C. 167 pp.

Lietritz, E., and R. C. Lewid. 1976. *Trout and Salmon Culture. Fish Bulletin 164.* State of California, Dept. of Fish and Game., Sacramento. 197 pp.

Sedgwick, S. D. *Trout Farming Handbook.* Seeley, Service and Co., London. 157 pp.

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