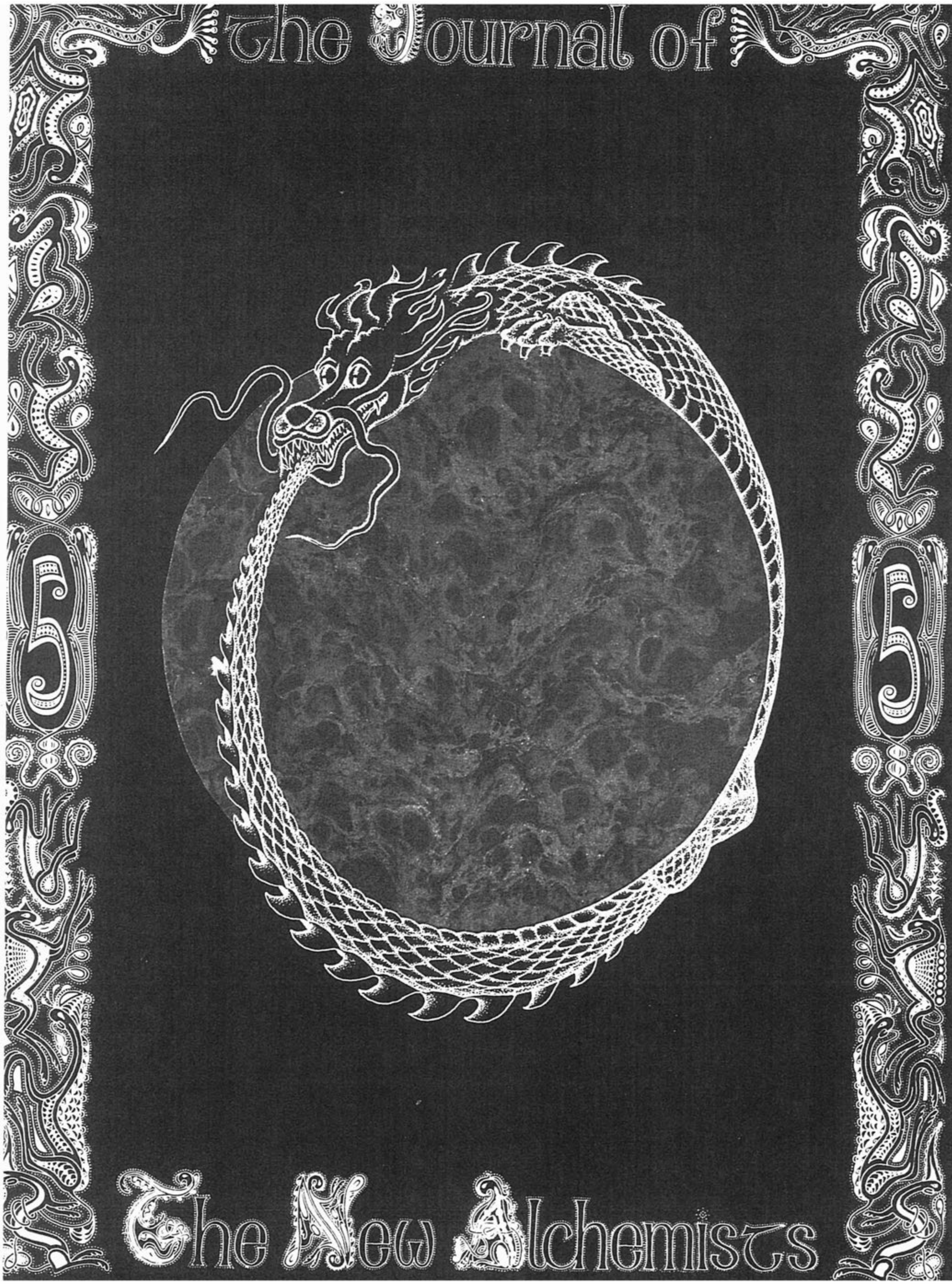
The Journal of
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The New Alchemists

Journal of the New Alchemists 5

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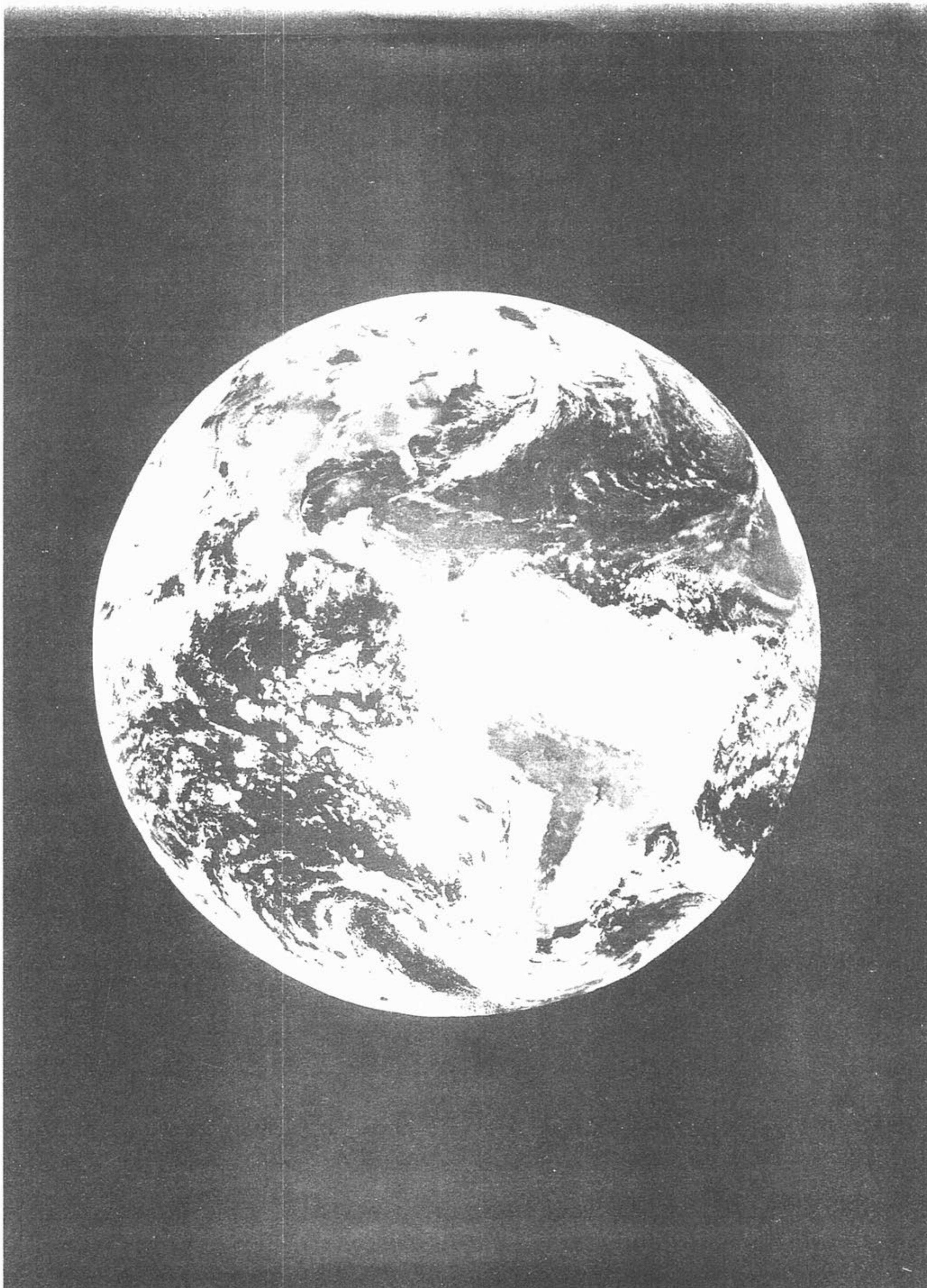


The publication of this Journal was made possible by a gift from Mrs. Esther Johnson.

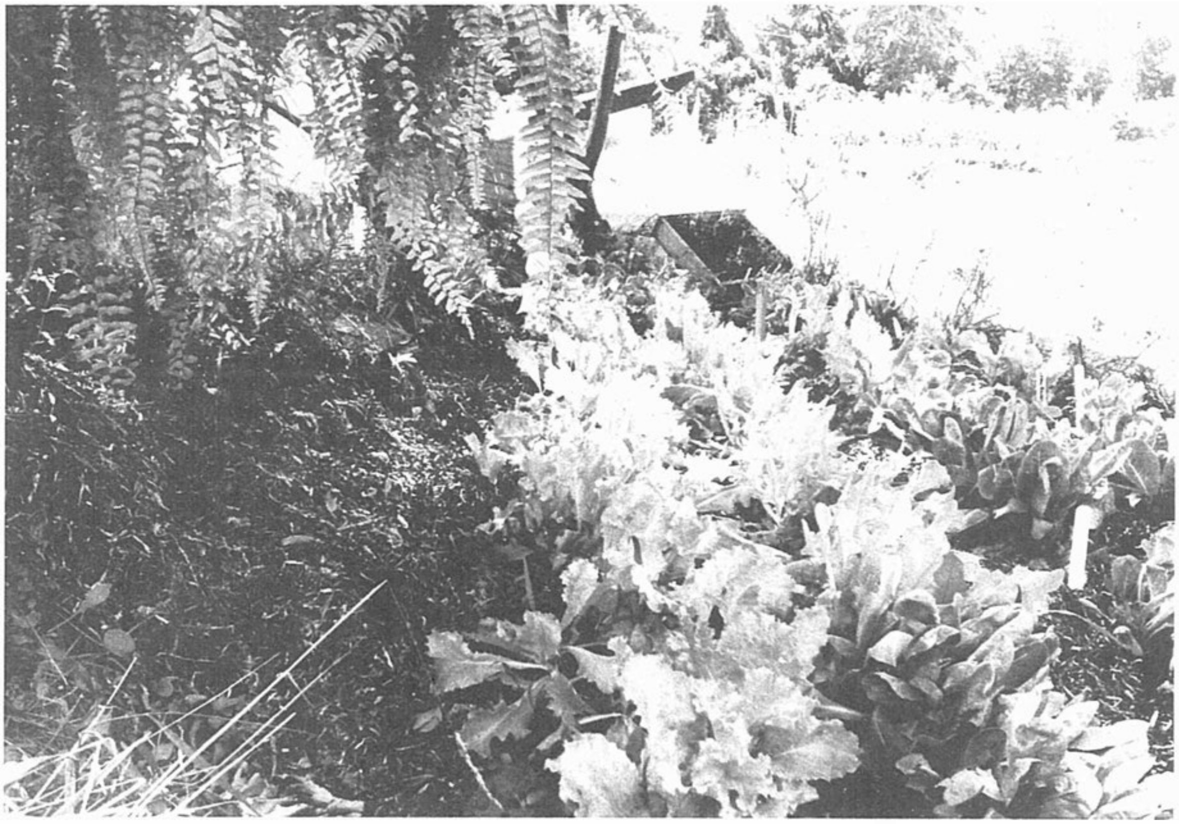


Photo by Ron Zweig

Old paint on canvas, as it ages, sometimes becomes transparent. When that happens it is possible, in some pictures, to see the original lines: a tree will show through a woman's dress, a child makes way for a dog, a large boat is no longer on an open sea. That is called pentimento, because the painter 'repented,' changed his mind. Perhaps it would be as well to say that the old conception, replaced by a later choice, is a way of seeing and then seeing again.

— Lillian Hellman, in *Pentimento*

The period reflected in the writing in this Journal has been quite unlike that chronicled in its predecessor, which was one of conspicuous milestones. The fourth Journal reported on the completion and opening of the Arks on Cape Cod and Prince Edward Island. We were able to announce the promising early work with solar algae ponds, and their potential for unexpectedly high protein productivity. It was a phase of fruition of much of our early work. For the first time, we had concrete evidence that the question of ecological analogues to industrialism, which is the underlying paradigm for New Alchemy, might be answered in the affirmative — would be, in fact, an affirmation of our ideas.

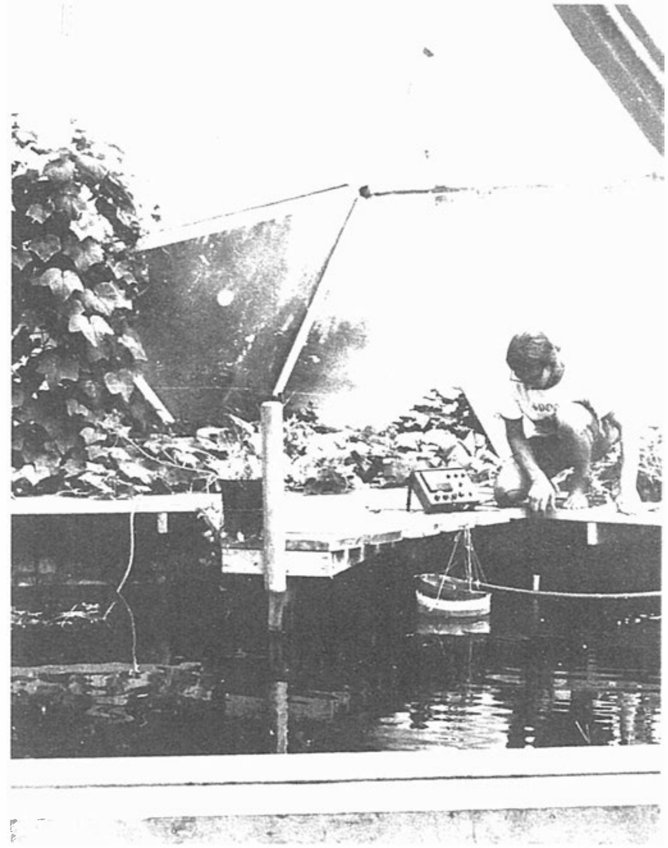
This should not and I hope has not led to hubris. A cautious and optimistic affirmation of the biological metaphor as a viable path for the future does not mean that we felt that we had, in the then seven years of our existence, sufficiently unravelled the complexities of the natural world. And so the efforts of the past year have been characterized by digging deeper; by trying to assess the earlier work and extend and integrate its implications and application. It could perhaps be considered a deliberate exercise in expanding perception.

The major new tool that we have acquired in the attempt to hone our perceptual skills is the computer. Keeping firmly in mind the homily that a system that cannot be modelled cannot be managed, and reminding ourselves that our fundamental goals have always been pragmatic — to find workable alternatives in the provision of essentials — it seemed advisable to try to deepen our understanding of the biological systems with which we work. We view

Photo on preceding page Courtesy NASA

our incorporation of the computer as an extension of mind. Human beings, in the main, tend to have a fairly narrow, inadequate and subjective ability to discern reality, even though individual range varies enormously. Jean Henri Fabre, the French naturalist of whom Meredith Luyten writes in the "Explorations" section is an outstanding example of someone with an ability to see that permitted him to know the world in a more profound than is usual sense. Yet, even someone with the breadth of understanding of Fabre has inadequate knowledge of the range of courses of action that will best enable humanity to sufficiently sustain itself on its crowded planet. Gregory Bateson observed that adaptability is a resource. The world being in the tenuous state that it is, and adaptability being hopefully a renewable and non-polluting resource, it seems wise to plumb it. The extension of perception and the integration of knowledge offered by cybernetics, which we are utilizing through the mathematical modelling of our systems on the computer and which hopefully will improve the way we think, could be seen in this light as an exploratory survival skill.

Unassisted by technology, exceptional perceptual gifts, the imaginative ability to synthesize aspects of reality and to communicate their insights are the province of the genius, the mystic and the artist. Brother David Stendl-Rast, in a talk on Art and the Sacred at the Lindisfarne Association, described the necessity of letting go of preconceived notions of reality in order to enhance one's apprehension. He said, "The moment you open yourself to reality, the moment you allow it to do something to you, you discover an order that is not your order. You discover in things an order that existed millions and millions of years before we ever came around; in persons you discover the mysterious order of the other." Brother David went on to say that the experience of facing reality often could be one of anguish and he used as an illustration Picasso's painting of Guernica after the shock of the first saturation bombing of a village during the Spanish Civil War. But, he pointed out that, beyond the encounter with pain, there was for Picasso and there is for the artist generally, whether the experience be one of suffering or of ecstasy, the act of creation that is ultimately an affirmation of reality, and Brother David quoted T. S. Elliot, "So the darkness shall be the light and the stillness the dancing."

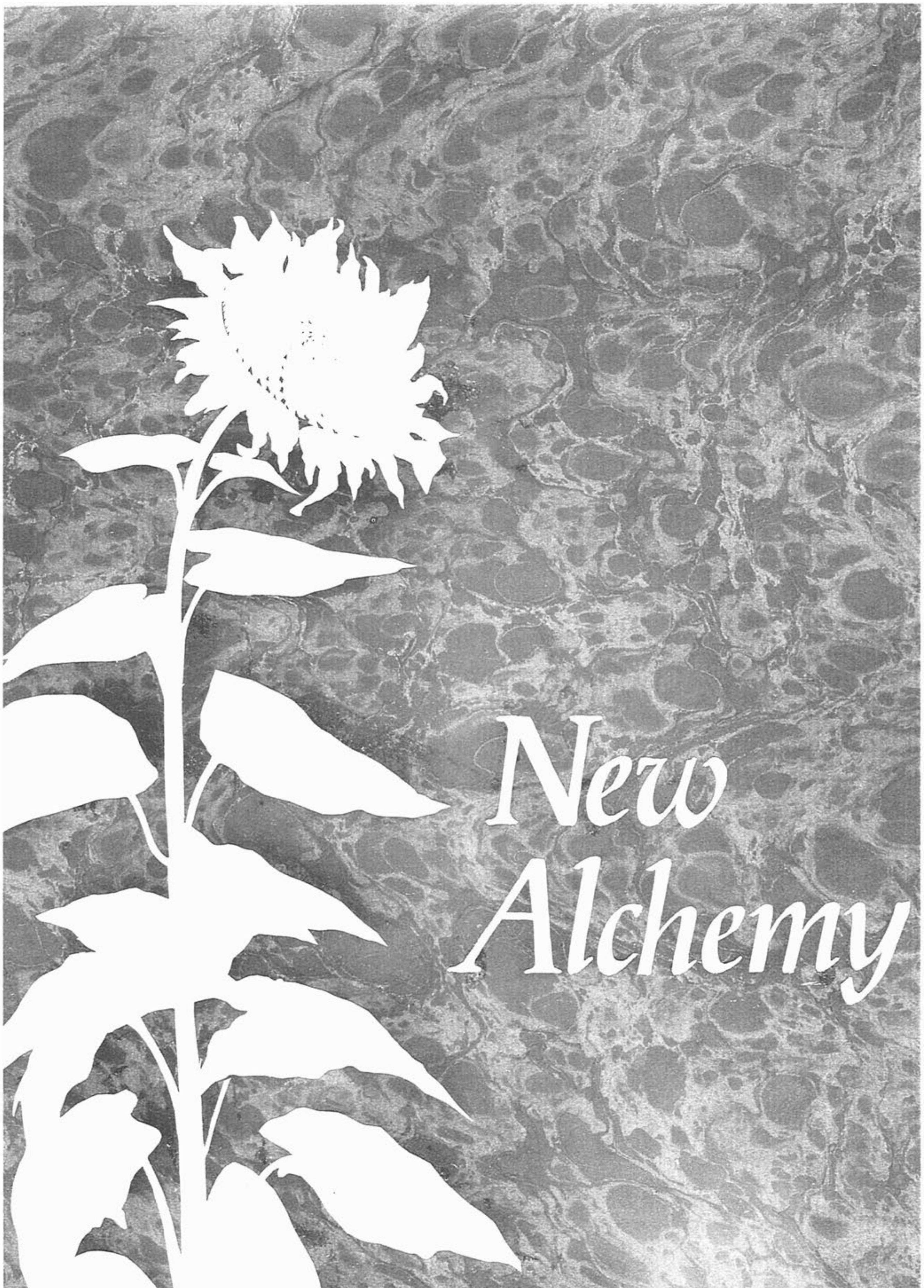


The human situation at this point in history is, in some ways, analogous to that of the artist. We are in a position where we must learn, as a species, in Gary Snyder's words to "look clearly into the wild and see our selfhood, our family there."

We have developed tools for extending our vision, for teaching us to listen and for deepening our understanding, all of which we can use in what John Todd has called "the sacred dialogue with nature", upon which we believe the continuation of human life to be contingent. We can evolve the vision, learn to see and see again and with our lives create an affirmation.

— NJT

Photos by Hilde Maingay


New
Alchemy

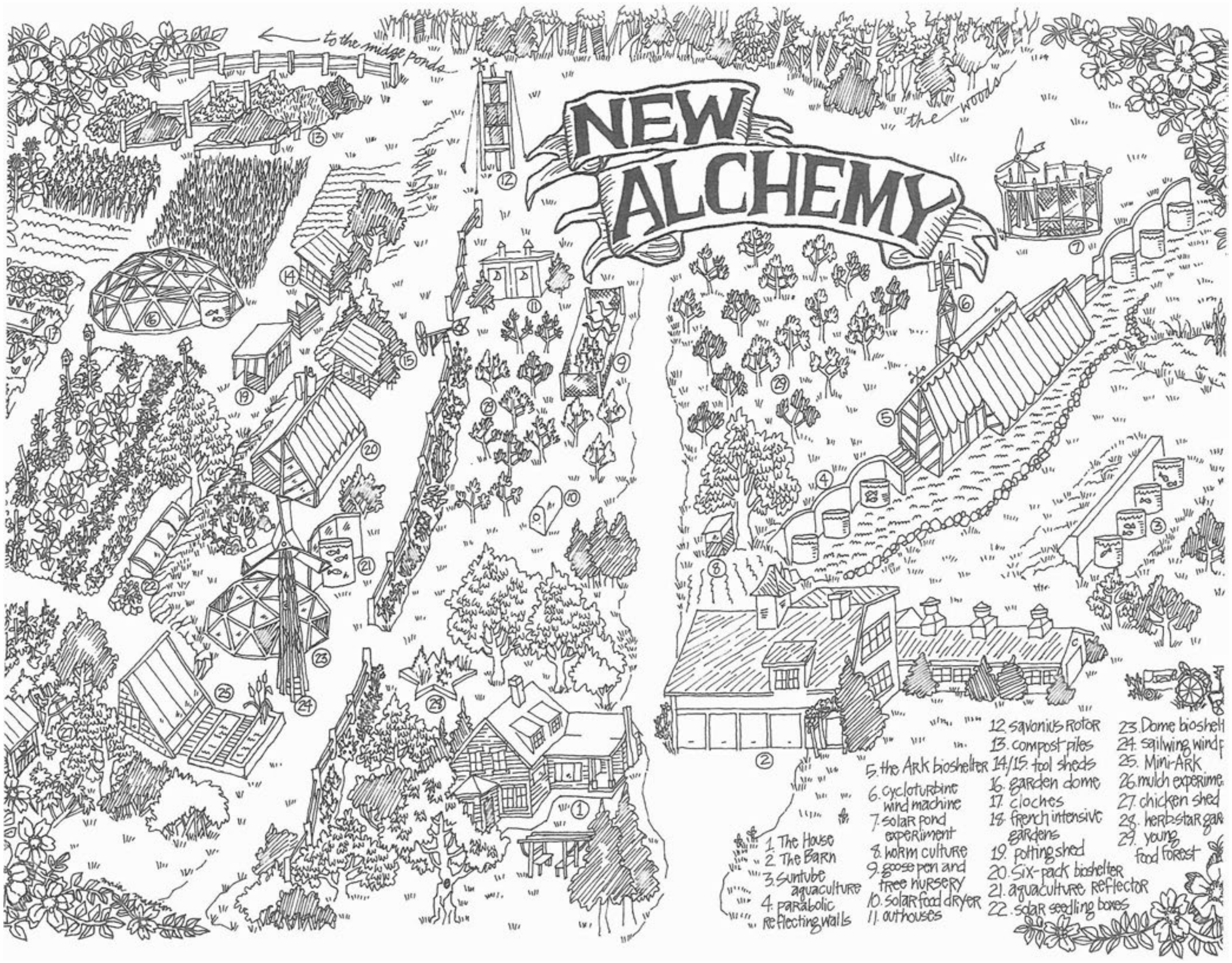
Not long ago we spent an evening looking at some films made during New Alchemy's early years. For old hands they were wonderful — nostalgic, funny! The children were so little. Everything looked so makeshift and tentative. Some of us were thinner — and, well — younger. The reactions of some of the newer people were interesting. One of them said, "Everything seems so established. I didn't realize that it hasn't always been that way."

For those of us who have been around for a long time, the evolution has been sufficiently incremental and gradual that, although we were aware of ongoing transitions, we had never really been confronted so concretely with the degree to which New Alchemy — and we — have changed. And yet, in another way, we are still the same undersized maverick organization pursuing a vision wildly at odds with the image still officially espoused by industrial society — building windmills, rather than tilting at them, and rarely sure beyond a few months of salaries or funding.

And, if it's not always quite as heady as it once was as much of the time, there are still the lovely days and periods that carry us through the more mundane ones.

The original idea of including a section in the Journal just on New Alchemy was to try to convey a sense of the place beyond the vision and the work. We have written of our births and deaths, our struggles with sex roles and heirarchy, our stumbling blocks, our triumphs and our feasts. We had to expand it to include reports from Costa Rica and Prince Edward Island. As we grow larger and more complex, all of this becomes increasingly difficult to capture. Yet this year again, while confronting our readers with PAVE PAWS and the rationale for computers, there remains, among all the seriousness and loftiness of purpose, the somewhat ponderous comfort conveyed in the essense of the "Terrible Joke."

— NJT



Overview — *Nancy Jack Todd*

JOURNAL PUBLICATION: GESTATION AND BIRTH

This is our fifth *Journal.* The first was published in September, 1973. It was preceded by a series of newsletters and bulletins which included John Todd's *Modest Proposal* and *Newsletter Three on Methane Digestors for Fuel Gas and Fertilizer* by Richard Merrill and John Fry. Looked at in one way, our publication schedule may seem a bit unpredictable, although only *Journal Three* has not made its appearance in the early fall. The erratic timing reflects our financial vicissitudes. There are times when we simply don't have the money to go ahead with printing. As I write this in late May of 1978, it looks ominously as though this could be the fate of the fifth *Journal,* which, like the third, could be delayed by what we hope is only temporary destitution. This also accounts for the delays in reprinting. At the present, the first, second and third *Journals* are out of print and, in spite of considerable demand, we can't afford to reprint them, although we have every intention of reprinting the second and third when it becomes possible. It seems less likely that we shall do so with *Journal One* although, nostalgically, we should like to.

Barring financial uncertainty, however, a fairly workable publication schedule, one that is in rhythm with our yearly patterns of work, seems to be emerging. It is, I think, obvious to readers that the *Journal* is not the product of a staff of writers, but is written by the people in the group who actually do the work reported in various articles. This means that, for the growing season, which can extend from late April into October and is also our season for Farm Saturdays and workshops and a minimal six-day work-week, it is out of the question for anyone to do any writing. Reports and articles must, perforce, wait until fish and gardens

Art by Maia Massion

are harvested and made ready for the winter and data are collected. With people already overextended, it would seem not only unrealistic but inhumane to set a deadline before January or even February first. To see one's friends hollow-eyed by Christmas feels a little unsettling. But this means that material is not ready for editing until mid-winter and, with the increasing number of articles, this takes several months. As articles are completed, they are relayed, a few at a time, to Claire Viall at the printer's for transferring to the Composer, after which the galleys come back to us for a final proofing. Meanwhile, the visual material which, again, is done largely by group members and is their second order of business, after writing, is collected and organized. With this, everything is delivered to Jack Viall, our printer and friend, and he and I do the layout. This usually takes place in late May or June and the *Journal* remains with Jack. He and Claire, who also is a good friend, have a small three-person print shop in West Harwich, and they run it with dedication and care, reminiscent of traditional New England crafts. By the time Jack has processed the *Journal* and it has been bound, the summer is gone, and we plan for delivery back to us by early fall. It remains to us to mail it, which is no inconsequential feat and usually an obligation met by the group en masse.

Because this schedule seems to have evolved almost of itself and is by far the most compatible with the rest of New Alchemy's work, we have come to think of the *Journal* as a harvest publication, coming, we hope, reliably at that time of year and garnering the work that we feel is ready to be passed on to our readers and friends.

LIMITS TO GROWTH - SORT OF

One of the most frequently asked questions of the informal, friendly kind that we receive at New Alchemy is regarding the size of the group. Incurably vague about these things (it would have been a grave mistake in personal mathematics for me to have had more than three children — I should have lost count), for years I have replied that we had a shifting population of about a dozen. This was a fair ballpark estimate, with all the comings and goings, and visits from fellow travellers, families, friends and volunteers who have come to work for us for a while. The dozen or so of my answer did not include the extended family or network of people who have participated as consultants, designers, engineers and advisors which, of course, comprises a much larger number and is even less susceptible to census-taking.

Lately it has become obvious, even to the most obtuse, however, that we have grown. Rather like one's children who often achieve a change in state rapidly and unexpectedly catching one somewhat off-guard, the gestalt of the group has changed. One way of telling is by weekly meetings during the winter when many people are often away on other projects, at which times we sometimes used to muster not many more than six or eight. This year, even with several permanent members absent, we counted eighteen, which must put us at about twenty-seven all told, counting volunteers, and we expect Kathl Whittaker and Jay Baldwin to join us in late 1978.

We hope with this to have achieved at least a temporary homeostasis. Our expansion so far has

Photo by Hilde Maingay

been necessitated by the size or the workload which could no longer be shouldered by the original numbers. We trust that we haven't initiated an unfortunate variation on the Peter Principle and that the work to be done will not, in turn, swell accordingly. Right now, it seems, and this I think is reflected in the articles in the *Journal,* that most of the niches, for the present, are filled. Tanis Lane, Denise Backus and Conn Nugent share the huge burden of administration and funding that formerly fell on Bob Angevine, John Todd, Christina Rawley and myself. Extending the scope of both the bioshelter and aquaculture research and thus helping Ron Zweig, Al Doolittle and John Wolfe have brought their computers and their skills. Joe Seale will work with Earle Barnhart in wind research, as will Jay Baldwin, who is a soft technologist of many parts. Kathl Whittaker is a soil scientist and will be collaborating with Hilde Maingay, Susan Ervin and Kathi Ryan. Our artist in residence, Jeff Parkin (cover) joined us last year to help Bill McLarney in his work.

Again, as a rough estimate, about twenty permanent members might be an adequate answer to the "how many" question for the next little while. If a loss of intimacy has resulted in reaching this size, it has been compensated for by the inputs of fresh thinking, different points of view, and new creativity that the recent arrivals bring with them. The only major inconvenience of the increased numbers is the wearying, corresponding growth in the number and length of meetings. The weekly meeting can now run to over four hours, as each of us goes on feeling obliged to get a word in. Survival skills for endurance have included the taking up of handwork by more and more people of both sexes. Bill McLarney often manages to get through them by sleeping for the duration – or most of it. But then, in retrospect, he always has.

NEW ALCHEMY, PRINCE EDWARD ISLAND

In September, 1976, the Ark, a bioshelter designed and built by New Alchemy and Solsearch on Prince Edward Island with funding from the Canadian government, was completed and officially opened, as described in last year's *Journal.* It has had, in such a short time, an eventful history and has attracted an undreamed-of number of visitors.

In spite of Prince Edward Island being a popular tourist spot, the majority of those who come to the Ark are neither sightseers nor dilettantes in search of novelty, but people who are troubled by inflation in the costs of essentials and open to the idea of alternative methods of providing them. Coping with the interest of the public at large quickly became more than a full-time job and this did not take into account the demand from various

Photo by John Todd

official bodies ranging from the United Nations to representatives of governments and other organizations from many countries, distinguished visitors and officials from departments within the Canadian government. It is difficult to pursue the paths of research and education simultaneously, especially with so many people wanting access to a structure of limited size that is also committed to housing plants and fish. Yet, from the outset, the Ark was a research project – not an answer, but a compendium of questions in such areas as the practicality of solar and wind energy and the possibility of intensive, ecological food production. It represents a shift in paradigm from standard modern housing, which is an ongoing energy sink and a source of pollution to the adjacent ecosystem, to a bioshelter concept which is independent in terms of energy, processes its own wastes and is a potential source of products useful locally.

Evaluating the possibilities of the Ark and realizing its potentialities is a research project involving years. We were, after the initial building grant, understaffed and underfunded to fulfill the obligations in research, education and public service posed by the Ark. Fortunately for us, there is, on the Island, an indigenous organization, comparable to and highly compatible with New Alchemy. It is directed by Andrew Wells, an Islander with an independent but remarkably similar vision to ours. His organization is called the "Institute for Man and Resources." After con-

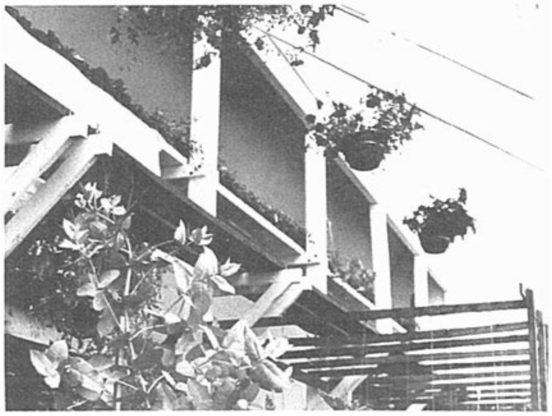


Photo by John Todd

siderable agonizing, we decided, because I. M. R. was in a much better position, both geographically and financially, to carry on the work on P. E. I., that we would turn the management of the Ark over to Andy's group, retaining some guidance over the direction of the research. The new director of the Ark is Ken McKaye. Nancy Willis continues to be in charge of agricultural experimentation.

We find ourselves happy with this arrangement. We are a small group, and, although we have grown larger of late, we are still stoutly trying to maintain limits to our growth. We also see ourselves as initiators and testers of ideas, not as administrators on a large or farflung scale, which inevitably involves, as Conn Nugent observed, the type of problems encountered by the Romans when they crossed the Rhine.

As things stand now, we have planted a seed. Whether it has found a benign environment remains to be seen. We have always hoped that our ideas, free for the taking, would be adopted, but also adapted by people to their own social and environmental milieu. The Ark belongs to Prince Edward Island and its people. It is for them to see which of the many possibilities it holds are relevant for them. But, because Andy Wells for a long time has been closely affiliated with the Island's Premier, Alex Campbell, and because Mr. Campbell, who has been extremely supportive of the ideas of New Alchemy and other future-oriented projects, has recently been re-elected to an unprecedented fourth term, we have hope that our seed has fallen on fertile ground.

PAVE PAWS

In the fall of 1977, some of us at New Alchemy, in greater and lesser degrees, embarked on a new adventure. We found ourselves in a position where we felt obligated, if peremptorily, to tackle yet another dragon – this time in the guise of a giant radar station under rapid and remarkably unpublicized construction at Otis Air Force Base, just five miles from the farm on Cape Cod. The radar is a Precision Acquisition of Vehicle Entry Phased Array Warning System and goes by the suitably sinister anagram of PAVE PAWS. It is one of the largest in the world and will be able to scan the Atlantic for three thousand miles to the north and south and to pick up an object the size of a car over Europe.

The challenge or threat that it posed to us is not unlike one that many people have encountered with nuclear power stations, in that the residents of an area, with very little forewarning, are presented with a project allegedly for their benefit, with little or no debate on the inherent health or environmental implications, or even whether they agree to having it in their midst. Nuclear power stations in general and the Seabrook and Pilgrim plants in particular find us in a comparable position, but we consider New Alchemy to be, in part, an anti-nuclear statement by dint of its existence and, to that extent, we are supporting the anti-nuclear movement. Then, too, our thinking is not that of a unanimous entity. Individual participation in grass roots and protest politics varies widely. Christina Rawley in particular has been active in the Clamshell Alliance and was one of those arrested at the first Seabrook occupation. Many of us went to the support rally for the second and will go again to the third. Opposing nuclear power will continue to be of major concern to us.

The situation with PAVE PAWS is slightly different in that, as of the fall of 1977, the dangers of exposure to microwaves or other frequencies of the electromagnetic spectrum causing non-ionizing radiation were not a part of public consciousness. It was only with the publication of a series of two articles by Paul Brodeur in the *New Yorker* for December 13 and 20, 1976, that much information began to reach beyond a few troubled scientists, researchers, technicians and medical people. With the subsequent publication of Mr. Brodeur's book, *The Zapping of America* in the fall of 1977, the public at last had access, in lay language, to a documentation of microwave technology and its military and non-military applications. Because PAVE PAWS is a local, even disconcertingly intimate issue, because it overtook us with so little advance warning, and because so little was known of the potential effects that it was considered a little uncouth to be too questioning, coming as it did cloaked in the mystique of a sacred cow – defense – it seemed unrealistic just to hope that it would go away. Christina and two of our volunteer staff, initially Carl Goldfischer and subsequently Gary Hirshberg, undertook to give a great deal of their time and energy to organizing a series of public meetings and a campaign to inform Cape Cod residents on the issue.

In this case, as in so many others, a question of appropriateness seems to arise. I have been at too many occasions at which one or another speaker will ask, with what I find lamentable jest, "Well, just what is 'appropriate technology' anyway?" And go on to stretch the credibility, or at best the common sense, of listeners with descriptions of any kind of industrialism as appropriate under some circumstances, usually in the name of relieving unemployment. The term "appropriate technology", it seems to me, is less useful as a definition than as a yardstick against which a range of technologies can be measured. At one end of the yardstick one would place all the unforgiving technologies that are inherently destructive of life – human life and that of the biosphere – now and in time to come, technologies that in Dennis Meadow's phrase, "foreclose all other possibilities." By this measure, nuclear power, nuclear weapons and large-scale attempts to tamper with global ecology, as with weather modification or giant solar power stations in space that would transmit microwaves to earth to harness for electrical energy, and the spectres of biological and space-age electronic warfare all align themselves as inappropriate to the point of being unacceptable. At the opposite end of the scale could be placed the gentle technologies that use renewable energies, cause little environmental disruption, have a reasonable net energetics ratio in manufacture and are applicable in meeting the needs of an area. Examples of this kind of technology in developing countries are some of the biogas converters and methane plants already in use and in the ideas of the Intermediate Technology Development Group, which has been under the leadership of George McRoby since the death of Fritz Schumacher. From our own work, the water-pumping sailwings described in this *Journal* or the formation of gley qualify as useful and non-destructive and therefore appropriate technology.

Then there is a whole sliding middle range where appropriateness must be judged by further criteria. In some cases like fossil-fuel based technologies, as exemplified particularly by extensive use of the private automobile, they may be seen to be transitional and fated to be phased out. While not directly lethal, their consumption of resources and long-range environmental destructiveness indicates they will need to be replaced or transformed. Genuine utility as opposed to superfluousness is another qualifier of appropriateness, with a large percentage of the products currently on the market subject to scrutiny. The stringent weighing of environmental and social costs relieves much of the fogginess from the concept. A comparison between a recreational motorboat, a private car and one of our bioshelters could be ranged along this scale. All use fossil fuels, as the structure of the bioshelter incorporates a fibreglass substance known as Kalwall which is a plastic product. The motorboat, as both fuel-consuming and excessive, would obviously be the least appropriate. The car, although a villain on many counts, is closer to a necessity, pending the revival of public transportation systems, and would come next. The bioshelter, although it has energy demands during manufacture, stops its fuel-consuming at that point and functions on renewable energies. In doing so, it represents a softer, more appropriate, even more intelligent technology. The idea of appropriate technology remains for the present a useful frame of reference in judging priorities and making decisions.

We deemed PAVE PAWS to be inappropriate, not the least for the unknown cumulative effects on the health of the residents of the area. To risk the disorders which plagued many of the staff of the American Embassy in Moscow and ranged from mild nervous symptoms to abnormally high, often pre-leukemia, level white blood cell counts, and an extremely high rate of cancer for continual electronic vigilance against hypothetical and, in any case, almost surely fatal attack, seemed a large sacrifice to demand of an area. It is hard not to see oneself as expendable.

Beyond the health question, opposition to such a huge incarnation of the war machine, even when labelled defensive, seemed obligatory. Paraphrasing Dr. Helen Caldecott, who spoke in protest at one of our public meetings, it is essential for people to become active in trying to deter the escalation of the arms race. With arsenals scaled to massive overkill for the entire planet, there are few points at which this collective insanity can be broached by ordinary people. We can, of course, accept our helplessness and let our destiny, perhaps as a species or a planet, be played out by great, amorphous forces; or we can act to try to change it. Occasionally, individuals like Anwar Sadat of Egypt have made gestures that exemplify the kind of imaginative leap of faith that could be mirrored on a small scale in one's own actions. At some point, opposition to planetary destruction has to cease to be theoretical, as is beginning to happen in the demands of anti-nuclear movement and in a much smaller way, in the struggle over PAVE PAWS.

As we go to press, Massachusetts Congressman Gerry Studds and Senators Kennedy and Brooke have called on the Air Force to make an environmental impact statement. This was not done initially, when the project was in the planning stage, and never would have been, had not hundreds of Cape residents insisted that the Air Force hear them. In the long run, this will likely only buy time, although comparable radar projects have been cancelled elsewhere after encountering local opposition. The fact that the Air Force was forced to acquiesce can be seen as a victory, however modest, for individuals against bureaucracy, as a statement of opposition to war and as a sign that, if sluggishly at times, democracy still works.

A TERRIBLE JOKE ABOUT THE NEW ALCHEMY INSTITUTE

There is a generally unacknowledged, but undeniably extant, aspect to life at New Alchemy that has rarely been written about. It is the terrible joke. Its status tends to ebb and flow, depending on how many of its practitioners are around at a time. The principal exponent and devotee is Bryce Butler, whose tales are unrivalled in their labyrinthian and excruciating qualities. But there is no question that the tendency, however deplorable, is infectious and, as everyone is more or less susceptible to colds, we fall victim to the urge to tell terrible jokes with a great range of responses. Bill McLarney has succumbed more than once. Conn Nugent is prone to do so and, from all advance indications, Jay Baldwin may be as bad as any of us. There are those who never do, of course, but our best, or at least most appropriate, terrible joke to date must be credited to Sandy Polanski, Susan Ervin's sister, whom we do not see often. Whether she is as subject to this sort of thing in more or less benign climates, I don't know, but she was inspired with the following while visiting Susan last summer.

It seems there was an old musician, long retired. In his day, no one could equal him on the horn (I'm not sure whether it was a saxophone or a clarinet). But the years on the road, the late hours and drinking had taken their toll and left him washed up and pretty obese as well. He hadn't lost everything, though. When he chose to, he could still summon up a sound from his horn with as much or more power or resonance as anyone – beautiful and rich.

The old fellow had a son who, in his way, was somewhat representative of his generation – a frail, weedy young man who subsisted largely on bean sprouts and wafted wheat germ. Yet, true to his heritage, he was not without musical talent. Although he could barely raise a note from the saxophone (or clarinet) his fingering was incomparably sensitive and delicate.

The two were sitting side by side on the front porch one torrid afternoon, attempting to practice and bemoaning their respective and collective fates. "Oh, Dad," sighed the son, "it's all over. We'll never be able to make music again." The old man looked unhappy for a moment, then rallied. "Never you mind, Son," he rumbled, touching him gently on the knee and, grasping his son's horn while the surprised younger man was still fingering, he blew a terrific blast, pausing only to gasp (to be read aloud!):

"Thin you. Alchie me. Instant toot!"

Well, it is indeed a terrible joke, but it's a wonderful terrible joke and, as has been said of humorists, it isn't easy – to go on paying the rent and make terrible jokes at the same time.

Art by Maia Massion

FARM SATURDAYS

We ask people planning to come to arrive by noon. At this time, there is a general introduction on the background, paradigm and ideas underlying New Alchemy's work. After this, everyone revives with lunch. We ask our visitors to bring food with them – a bit more than they are likely to eat themselves and, preferably, something like bread or fruit or cheese that is easily shared. This way there is almost always enough and people get a chance to meet each other as they serve the food.

The workshops proper begin at one-fifteen to one-thirty, after a clean-up. There are usually two, sometimes three, taking place at once. The topics cover our basic areas of research and, accordingly, are on various aspects of agriculture, aquaculture, energy and bioshelters. The specific subject for each of these varies from week to week. Pest resistance or agricultural forests may be discussed under "agriculture", cage culture or semi-enclosed systems under "aquaculture." There is usually an additional workshop on the social and political implications of alternatives which can range from feminism to the opposition of nuclear power. It is our intent that these sessions be genuine discussions and not lectures on our part. An exchange seems to us a more genuine and rewarding form of communication.

Photo by Hilde Maingay

Coming to New Alchemy

– Conn Nugent

Photo by Adolf Baker

A lot of people who want to improve the social arrangement of things talk about "human needs." They suppose that the best way to meet human needs is to provide subsidized "human services." Education, health care, legal aid, counseling, public recreation, daycare. These are good things, mainly.

But it has occurred to other people that reformers should concern themselves with production as well as services. Producing useful objects in a benign setting can be rewarding work and the best of therapies. I like William Morris's old notion that the greatest general good would be enjoyed by a citizenry which lives simply and tries to satisfy itself through an egalitarian arrangement of fruitful work, shared values, and fidelity to nature.

I came to New Alchemy because I believe it is designing tools for a world in which that notion might be realized.

The irony, maybe double dealing, of all this is that I am a human services man myself. My job record is a collection of standard liberal impulses: youth work, Peace Corps, criminal defense, family planning, private philanthropy. I have a law degree and a self-image as a pragmatist. My move here strikes some old friends as odd, quixotic, anti-historical.

Maybe that's because many of those friends, left wing and right, share a common image of socio-economic structure: complicated division of labor, centralized control, capital-intensiveness. I'm drawn to John Todd's words:

> "It is becoming clear from the recently growing knowledge of living systems and from general systems theory that it is the structure, or morphology, of a system that determines its behavior and subsequently its fate. The coefficients or parameters within a system determine only rates or relative dominance."

Somewhere down the line — in a way, I don't care whether it's thirty years or a hundred and thirty — we are going to run short of fossil fuels. We will either maintain the current structure through the intravenous of new power sources (probably nuclear) or we'll need a new structure. Unless we plan well, either eventuality will cause enormous dislocation. The poor would get it in the neck. I'm for a non-nuclear alternative and for a gentle, equitable transition.

That a no-nuke future will demand fewer consumer services and a more widespread productivity looks likely. The challenge seems to be to make things fair and comfortable. We can return to the pre-industrial era easily enough, and probably gain some peace of mind in the process. But we don't need the early mortality, squalor and social hierarchies of those days. Far better would be to use our own luxurious oil-times to devise technologies and designs that will permit a new socio-economic structure that could marry the shared values and sense of place of, say, medieval Europe, with the material decency, democracy and intellectual freedom that we demand today. I tend to think the best society will be one that requires its citizens to do a lot for themselves. For that to work, those citizens will have to be capable and informed and free from the fear of social dominance. It could be that what we need is a national order that, like Marx, prohibits privilege, but, like Jefferson, leaves much to an educated yeomanry.

I don't know. As I said, New Alchemy is in the tool business. In a sense, our work here is to create options for grandchildren.

A final consideration, less mega-think. I always seek enjoyable work. "Work which is pleasure, pleasure which is work," as Morris said. Work at New Alchemy isn't utopian, but it's got law firms beat to hell. I like being here. I like bringing my six-month-old boy to the office, working some Saturdays, skipping some Tuesdays, digging in the garden and lugging junk and writing papers. I like the religion of this place: there is an explicit devotion to the integration of ourselves and the earth. It is very moving.

Calculating Engines

— Albert M. Doolittle, Jr.

It may come as something of a shock or, at the least, as a surprise to some of our readers to learn that New Alchemy has acquired two computers. While not trying to redefine the term "appropriate technology" (the definition of which is the subject of some debate anyway), we felt that the area of computers, microcomputers in particular, through decreasing cost and increasing usefulness, was redefining itself and might not be out of place under the rubric of appropriate technology. To understand this, the image of a computer in a room filled with large machines tended by equally large numbers of people must be put aside. High technology electronics has miniaturized and simplified sophisticated machines such as computers to a point where they are no longer the dominate entity in a human/machine interaction. Because New Alchemy has become a research institute that generates large amounts of data yearly, the data must be collected, reduced, verified and collated into publishable and usable form.

Over the last ten years, there has been a revolution in electronics. Catalyzed by space-race war technology, transistorized circuits have been so reduced in size that well over 50,000 transistors can be placed on a single silicon wafer ½-inch square (1.61 cm.sq.) or smaller. This process, called Large Scale Integration (LSI), makes it possible to produce for one hundred dollars hardware that formerly cost hundreds or thousands of dollars. Commercial applications like pocket calculators and digital watches have both accelerated the technology of mass production and driven the costs down to less than ten dollars at the retail level. Designers have been shrinking the size of computers so that the computing capability of large computers can be packaged in a box the size of a typewriter at very low costs. We are seeing a descending cost-size factor and, correspondingly, increasing performance factor which portends LSI electronic systems as a major force in shaping the future. LSI production is not confined to major technology producers. Many devices are made in Malaysia, Korea, the Philippines, Taiwan and Hong Kong. Although cheap labor is obviously being exploited, this does indicate a broad base for the production of such a high technology. A further example of this is in the quote of Koji Kobayashi, President of Nippon Electric Company, following a 1975 tour of the Peoples Republic of China, that the Chinese were fast approaching "the world's highest level in production of high capacity LSI's".[1]

There is an interesting anomaly in LSI production. A term called "Creative Quotient" (CQ) must be defined. In a manufacturing process, CQ is the amount of creativity or flexibility of use in the product passed on to the end user. Examples might be modelling clay and a manual can opener. Modelling clay is simple to manufacture technologically, yet retains a high degree of creativity (high CQ). The can opener requires more manufacturing in terms of technology and decreases in creativity (low CQ). Although it is possible to open bottles with a manual can opener, as one goes higher on the manufacturing scale to an electric can opener, that capability is removed. Although not a hard and fast rule, in general, as a product becomes more complex, creativity is increasingly relegated to the creator rather than the user of the product. Because of its inherent design, we are, a priori, forced to press button A before button B to get the thing to work. More analytically stated, Creativity Quotient is inversely proportional to the manufacturing complexity as shown in Figure 1.

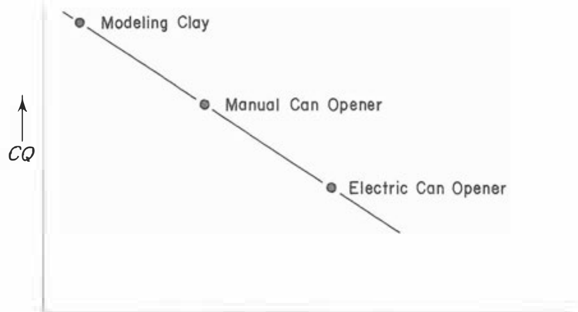


Fig. 1

With LSI technology, the case is reversed. Digital watches, as LSI devices, would be on the low end of the spectrum. They are the simple products. For the user, they are easy to operate, but they have a low CQ. There is little owners can do with them beyond telling the time or date. Calculators are higher on the scale, leading to a higher CQ. Although limited in the functions they can perform, some potential creativity remains after they have been manufactured. The user can create new problems or games which, with the programmable calculators, can be quite complex. The calculator is essentially a microcomputer with a fixed program residing in its memory. When turned on, the program begins to execute on the calculator's computer. If the users have access to the stored programs and can change them to suit their needs, they are in possession of a high technology product with immense creativity or flexibility (i. e., high CQ). This aptly defines the microcomputer. The user communicates to the computer in a mutually understandable language, such as Basic or Fortran or any other interactive language, and the computer performs the task or calculations.

Looking back at Figure 1, LSI technology could be added as in Figure 2.

As the technology becomes more complex, there is an inflection in the curve as the CQ rises with increased technology. This means that, as higher technology devices are produced, their control is reverted back to the user. Rather than viewing the complexity inherent in such technology as enslaving, it should be seen as a serviceable tool.

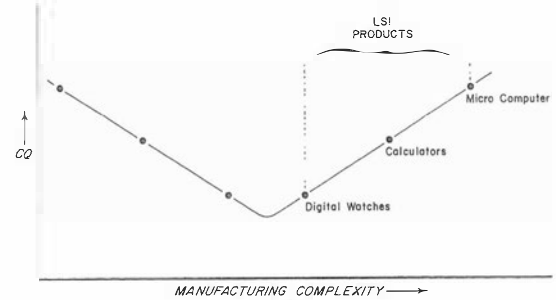


Fig. 2

Access to this type of complexity lies through programming. This should be considered a learned skill. There are at present approximately 60,000 home computers in use. Many children have learned to be computer programmers. Once the knack has been acquired, the power of the processor belongs to the users to do what they may.

At New Alchemy we have used our microcomputers to design data acquisition and control programs that collect and store data for later analysis. We also have programs to analyze and plot the data. We are not trying to replace ourselves as observers and participants in our experiments, but we do use them to read instruments and turn on pumps, open valves and control vents. They cannot smell, taste or see, but they can measure temperature, pH, sunlight, humidity, dissolved oxygen and many other physical parameters twenty-four hours a day.

In determining our computer system, we had two requirements that were somewhat mutually exclusive. In the first place, we wanted a low-cost data collector which was compact and able to withstand hot humid environments like that of a greenhouse. Secondly, we needed a system that could store large amounts of data and had programs available to reduce and analyze this data. Our solution was to separate our prerequisites into two separate computers.

We approached MICROLOG, Inc., of Guilford, Connecticut, with the idea of a small inexpensive data collector with the flexibility to collect the type of data we wanted without having to precondition our signals. This meant that we would design a module to read soil moistures, for example, directly from the sensor rather than from a box into which the sensor is plugged. All the sensors will plug directly into the computer. The economics of this type of set-up lie in the fact that a computer can read several sensors for the price of one signal conditioning box.

Our second requirement was met by a small PDP11/03 computer manufactured by Digital Equipment Corporation. With it we can communicate, using a high level language like FORTRAN-IV or BASIC and store the data on floppy disks which are essentially magnetic tape in the shape of a 45 RPM record. Our data can be plotted on a video screen and copies made of the plots for future reference. The two computers are linked as though they were computer terminals. The PDP11/03 requests data from the microcomputer which, in turn, selects the channel, reads the value and transmits the information back to the PDP11/03. The PDP11/03 then further processes the data, stores it and subsequently displays the processed data on the video screen. (See Figure 3).

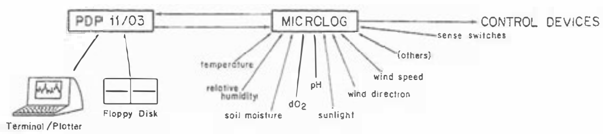


Fig. 3

Using a terminal type of link gives us added flexibility in that a regular terminal can be substituted for one of the machines. The PDP11/03 could be replaced by a terminal or recording device. The micro would then act as a small stand-alone data collector. The data could be stored on cassettes or on similar media and later be transferred to a computer for analysis. In fact, the microcomputer itself could be used for simple analysis.

The real power of computers in collecting data is derived not from the collecting and processing aspects, but from the ability of the computer to make logic decisions at the same time as it collects the information (called real time interaction). Not only can the computer read the temperature, amount of sunlight or other parameters, it can do something about them. The response might vary from typing a message to collecting a problematic situation. For example, if the temperature is too high, it will open a vent. That is a simple task and certainly does not require a computer. But more complex tasks, if a computer is not used, require extremely complex logic systems and can be very inflexible. For example: if the sun is bright in the morning, the air is warm and the time is 10:00 A. M., the vents should be opened so the building can get a jump on anticipated heat from the afternoon sun. If the sun is bright and the air is warm but the time is after 3:00 P. M., the vents should be closed or kept closed to conserve the heat. However, if the temperature goes above a certain value, no matter what the time of day, the vents should be opened. Conversely, if the temperature is cool, the vents should not be opened even if the sun is bright. The task can be performed by a wired-up logic, but it is interesting to look at the simplicity of the program. (See Figure 4.)

Figure 4

```
    WARM      = 20     ; degrees C
    SETTEMP   = 30     ; degrees C
    BRTVAL    = 50     ; mw/cm2
TOP READ TEMP, SUN, TIME
    OPEN = FALSE
    IF (TIME < 1600 AND TEMP ≥ WARM AND SUN ≥ BRTVAL)
        OPEN = TRUE
    IF (TIME ≥ 1600) OPEN = FALSE
    IF (TEMP ≤ WARM) OPEN = FALSE
    IF (TEMP ≥ SETTEMP) OPEN = TRUE
    IF (OPEN = TRUE) CALL OPENTOP; routine to open vent
    IF (OPEN = FALSE) CALL CLOSETOP; routine to close vent
    GO TO TOP
```

Other examples pertaining to non-mechanical systems such as the aquaculture systems could be cited. The computer could calculate a day's requirement of supplemental feed given the amount of sun and the estimated photosynthetic activity in the solar-algae ponds. It could advise and inform of important occurrences and act as an assistant.

With very little hardware, the computer can perform multitasks and collect data. We hope to make the understanding gained from these tools available in non-computerized forms such as operational manuals for bioshelters. We are not designing environments which require a computer for maintenance, but we do see it as a useful tool for studying complex systems.

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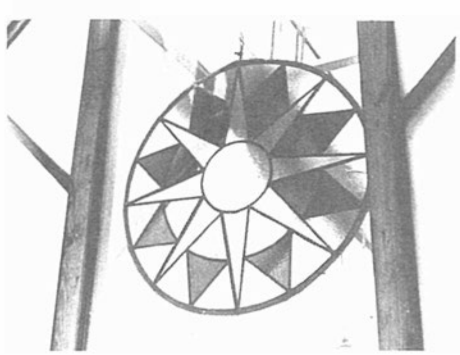
Photo by Hilde Maingay



On the Cryptic Phrase "Mathematical Modelling"

— *John Wolfe*

Several projects at New Alchemy now involve mathematical modelling. Joe Seale has developed a model of the thermal processes in the PEI Ark which will be tested against reality and refined over the next year; Colleen Armstrong is collecting data in the Cape Cod Ark on aphid outbreaks and the subsequent infestation of the aphids with a fungal parasite in order to model that phenomenon; and the author is part of a three-year project to model and optimize the solar aquaculture systems.

What are these things, mathematical models? There is such a wide variety it is hard to pin down a definition, but let me try: a mathematical model is a set of mathematical statements that describe the relationships between elements in a system.

Robust mathematical models can serve four purposes:

1) organize and tie together knowledge,
2) reveal the logical implications of that knowledge,
3) direct research by pointing out which important relationships are not yet well-defined, and
4) guide action by showing how changes in particular relationships or elements affect the rest of the system.

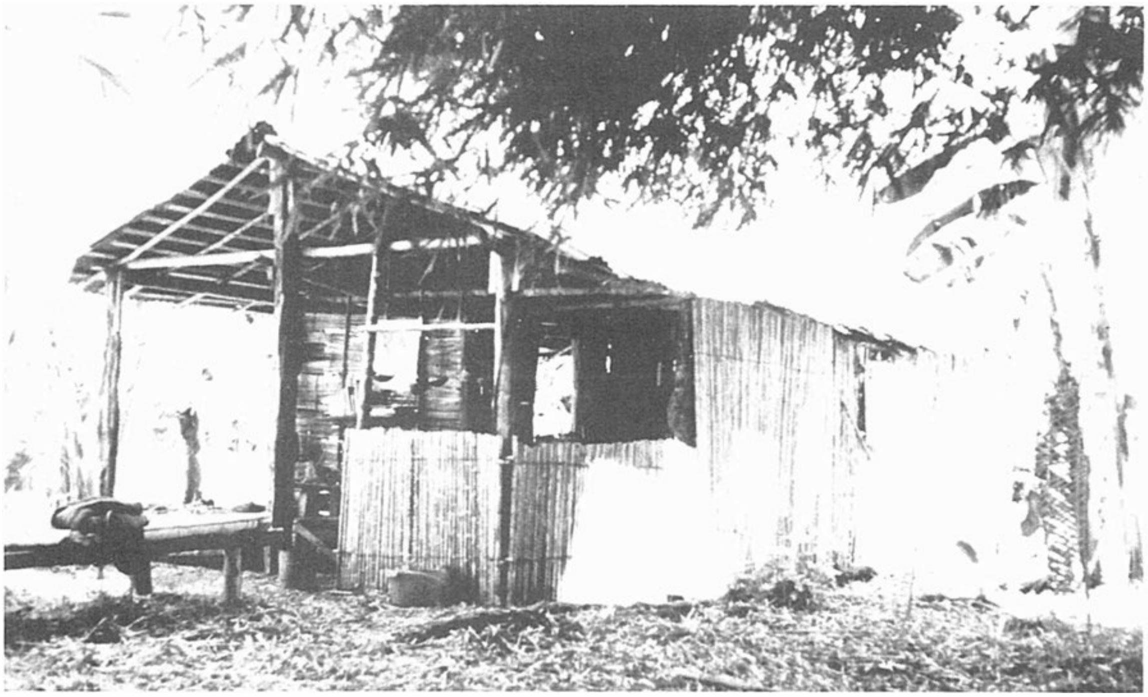
In other words, a good model enhances one's understanding of a complex system.

To avoid being an academic exercise, a model should be action-oriented; it must be directed toward solving a problem. In the aquaculture modelling project the problem is to maximize the growth of edible fish protein while minimizing the capital costs, labor, non-local energy inputs and commercial feed.

The mathematical tool one picks to model a system is crucial. One must avoid being limited to one mathematical method, or as Dennis Meadows puts it, "If all you have is a hammer, everything looks like a nail." At this point it appears that system dynamics offers the most appropriate approach for analyzing the ecosystems in bioshelters. System dynamics was developed to analyze feedback systems, and the essence of most ecological systems is this complexity. For instance, when our fish cut back the algae populations they, in turn, curtail their own growth. This is self-limiting, or negative, feedback. On the other hand, by cutting back the algae densities the fish allow more light to enter, spurring faster algae growth and thus more fish growth. In addition, the fish keep important nutrients in circulation, with the same result. Both are examples of positive feedback. Combined, positive and negative feedback loops exhibit an infinite variety of behavior, including oscillations, overshoot and collapse, and growth to a plateau.

Other mathematical tools, such as analytical solving of differential equations without using a computer, can model feedback systems only as long as the feedback loops are few and linear. Unfortunately, biological systems seldom contain linear relationships. For instance, the rate at which a tilapia in our solar ponds eats algae may increase steadily as algae densities increase, but beyond a certain point the fish becomes satiated. Thus the relationship between ingestion rate and algae densities is nonlinear. In mathematical jargon, system dynamics discretely integrates, or numerically simulates, nonlinear differential equations involving feedback.

As of this writing, John Todd, Al Doolittle, Ron Zweig and I are beginning to model the dynamics of the solar algae ponds. Hopefully, the model will guide us beyond the factors that presently limit fish growth in our ponds, but this isn't our only approach. This summer will witness the grand race between New Alchemists for the creation of the most productive solar ponds. It will be a race in more ways than one, for the computer will be churning out mathematical simulations, trying to find the optimum system too.



Costa Rica-1977

– William O. McLarney

This year's tale of Costa Rica cannot match its predecessor *(Journal Four)* for drama; there are no nefarious characters like "Farmer Man" lurking behind bushes, no squatters to evict, not even any major reverses of fortune. But for us it was a more exciting year than 1976, and the happy excitement, based on accomplishments, was shared with our neighbors. I only hope I can make a story without villains (though not altogether lacking in clowns) exciting to our readers.

Things got off to a pleasant start in January, when Susan and I arrived to find that Tony Lavender had taken splendid care of the place. The house had been improved, the soril field (again *Journal Four*) well tended, more fruit trees set out and – a first for NAISA – there was *food* in the vegetable garden when we arrived. A particular and surprising success was mustard, which provided us with abundant greens well into the dry season; tomatoes, cucumbers, peppers, malabar spinach and collards also did well.

With the guard changed and Susan and myself settled in, the first order of business was to call a community meeting. We were introduced at the meeting by Geronimo Matute, president of the Junta Directiva of the Asociacion Integral de Desarollo Comunal de Gandoca y Mata Limón. Those present bore with my Spanish, which is strictly "de la calle" (street Spanish) and certainly no act to follow Matute's poetic, oratorial style, while I explained that we had received a grant from the Arca Foundation for work within the community. For most of the people there it was the first admission that "los gringos" were there for more than the fun of it. I went on to describe the various areas in which we could contribute knowledge and experience in putting the money to work (vegetable gardening, fruit tree cultivation, reforestation, expansion of the soril project and fish culture), asked for comments or other ideas and indicated that visitors to the farm were welcome.

Response at the meeting was polite, but not notably enthusiastic; there were other community issues to discuss – maintenance of the foot trail which serves the community, possible stationing of a Guardia Rural (rural police) office in Gandoca, etc. But, beginning the day after the meeting, people began popping up. It soon became clear that by far the greatest interest was in fish culture.

Fish culture is anything but established in Latin America, and much of the fish culture that has been developed has suffered from entrepreneurialism and thus failed to serve the nutritional needs of the people. In Costa Rica, for example, there has been a well-run fish culture station at Turrialba for ten years. The station has somehow managed to develop itself into a money-making business for the local municipality. But the extension work visualized by the various agencies which have contributed to the development of the station (FAO, the Peace Corps, The Inter-american Institute of Agricultural Science, The University of Costa Rica and the Costa Rican Ministry of Agriculture) has simply not materialized. Small farmers around Turrialba do not grow fish and, in other regions, campesinos have only the vaguest idea of fish culture.

So we were surprised when seemingly the most "radical" of our ideas was the one which most stimulated the community. What we didn't know then was that, for the first time, Costa Rica has a chief of fish culture within the Ministry of Agriculture. Under the direction of this man, Herbert Nanne, Jr., several new aquaculture stations have been established and advisers from Taiwan have been brought into the country. Sr. Nanne, convinced of the importance of developing fish culture at the economic level of the campesino, has initiated a campaign of familiarizing Costa Ricans with the concept of fish culture by means of the one form of media which reaches all Costa Ricans – radio. So we had unknowingly planted our seeds on fertile ground.

We asked for volunteers, preferably young people, to train in fish culture. Two young men, Oscar Cerda, age 23, and Llunier Vallejo, 19, stepped forward. We chose to take on Oscar first, since Llunier had a year to go in high school.

Our first task was to construct ponds; Oscar announced with some pride that his father's profession had been "palero" (literally, shoveler), and so he had had a certain amount of experience relevant to the job. It was decided that Oscar would act as "foreman", directing the physical work and seeing to the selection of workers from the community, while I would plan the construction and supervise the biological aspects.

The problem of where to locate ponds was solved when Matute donated about 1,000 square meters of his land, fortuitously located just over the fence line from the NAISA farm. The area, which had been converted into pasture, was low and swampy. One ordinarily sites fish ponds on high ground to facilitate drainage. As it happened, this particular low area had still lower ground at one end, so won out over other possibilities by virtue of its convenient location. We also considered important the fact that it drains directly into the Caribbean (only about 200 yards away) so that there is no danger of any escaped tilapia creating ecological problems in adjacent bodies of fresh water.

Our fish culture system is to be similar to the "Campesino Fish Culture Units" of Anibal Patiño in Colombia. (See *Journal Three*). Even before beginning work on the ponds we planted about a hectare of fish food plants, principally melanga and camote, both of which produce tubers edible by humans or hogs, in addition to the leaves to be fed to the fish. Later, Oscar planted a forage plant known as ramio, provided by Raul Bonilla (about whom, more later), and this year we hope to introduce comfrey.

Oscar assembled a work crew, ranging in age from 16 to 72, including Llunier, who was on vacation, for our first assault on the pond site. We agreed that it would be best to pay the workers the standard wage for day laborers in the area. A point might need clarifying here. One might argue that a community development project should not pay workers from the community, but rather proceed on a voluntary basis. Such an attitude, while debatable in the United States, is simply not tenable in Latin America when people are living close to the line economically and full days or weeks of their time may be needed. Sometimes financial support in the form of wages can be the key which permits people to test ideas when otherwise they would be forced to reject the gamble.

The first task was to cut and remove the overgrown pasture grass so that we could see the contours of the land. We found two more or less natural pond sites, but also a disconcerting number of vertical and horizontal tree stumps and trunks. We laid out two ponds and the appropriate drainage ditches, incorporating as many as possible of the trunks and logs in dams, dikes and ditch walls. Then we set to extracting the rest with shovels and pry bars. I concluded there were no faint hearts in the crew when I discovered the appalling frequency with which coral snakes emerged and were dispatched with machetes. Meanwhile, Matute was fencing out his curious cows. Finally, on February 23, six days after the official opening of the project, we got down to the business of making holes in the ground, using the constantly breaking shovels which are depressingly typical of Central American hardware.

From the start, Oscar proved himself an ideal foreman. Faced with a work crew of men mostly older than himself, he managed to direct the work without creating major antagonisms, listened to advice when someone else knew better than he, and never pulled rank when it came to his share of the physical work.

The size and composition of the crew varied. During one week, when the whole community was involved in a major bean harvest, it was just Oscar and myself with shovels. More often we had five to eight workers. The attitude of most of the men was a joy. Some of us here in the States, if we have put in time with grousing, loafing, clock-watching work crews or if we have been ordered as I have by a foreman to slow down so as to make an easy job last, are prone to think that joy in manual labor was invented by the counterculture. A few weeks on a job like ours in

Costa Rica would straighten that out. The kind of men we had in Gandoca is capable of working long, hard hours without complaint and will exhibit a ditch well dug, with a smooth bottom and neat, square walls just as pridefully as a skilled Gringo carpenter might display a handsome desk.

This pride is borne lightly. Our work and its goals were serious, but the pond site was a place of laughter; mud fights were not unheard of. I was the butt of perhaps more than my fair share of the humor. It can be embarrassing when a fellow half your size throws a piece of sod at you and you catch it and find you can't even *lift* it. More than once I found myself plastered against a dike with tufts of grass apparently sprouting from my chest, while everyone else roared.

There was verbal humor as well; one day I suggested that if we could just locate a market for mud, we would all be rich. Matute allowed that they would probably make good use of it in Holland, and the rest of the day was spent hatching schemes for exporting mud.

Once in a while we would slip and take on a worker who wasn't up to standards, and that could be cause for humor, too. One such fellow was nicknamed Chiriquano. He was strong enough and competent enough with shovel, axe or machete, but had a distaste for mud – an attribute which became increasingly inappropriate as our task progressed. At first I was worried; here was one man receiving the same pay as everyone else, but avoiding the "dirty" work. What would happen to our morale? Oscar handled it without a harsh word. Sometimes we would encounter a giant log requiring our collective strength. "We need your muscle here, Chiriquano." And, with amazing frequency, he would draw the deep end or the end that would give way and pitch him headlong with a resounding splash. When I remember Chiriquano my clearest image is of his disconsolately trying to rinse his socks in the muddy water, while the rest of us look on with great solemnity.

But perhaps the best index of the workers' attitude was not in their physical performance, but in their intellectual interest. Recognizing that in all disciplines there are theory and practice, and that our little aquaculture exercise was outrageously imbalanced on the side of practice, we decided to initiate a series of weekly after-work seminars in the theory of fish culture and related facets of biology. We settled on Wednesdays. I had in mind that these sessions would primarily be of interest to Oscar and Llunier, but we opened them up to anyone who wished to come.

The first Wednesday, it rained all day. By the end of the day everyone was drenched and shivering. To my amazement, the entire work crew stayed to listen to me carry on for an hour in bad Spanish about food chains, polyculture and the like. Attendance remained high; today there are more than a few people in Gandoca and Mata Limón who know such things as the interrelationships of soil fertility, light, phytoplankton, and fish production, or fish culture methods used in China.

Even though we had planned the work for the "dry" season, rain was the bane of the project. An especially heavy spate of rain came just after we had finished cutting and raking the grass and removing the stumps. We had begun to remove the sod from the bottom and pile it up to build the pond banks. I was ready reluctantly to take a few days off. All my Gringo experience said that you don't dig sod in a flood. But "No", insisted Oscar, "ya esta mas facil" (It's easier now.) And we waded into the swampy mess with machetes. Thwok! Thwok! The sodden sod was cut into blocks and floated to shore, eliminating a lot of lifting and carrying.

I don't want to come on as though we were a bunch of heroes or to bring on boredom in talking about the hardship of the task, but I think it should be understood just how important it is to some people to build a fish pond and what a "day's work" means to them. From the time the grass was cut until construction was finished, everybody spent eight hours a day knee to waist deep in mud which I described in a letter as approximating a mixture of "hot oatmeal and chicken shit with a little rubber cement on the bottom." Temperatures were usually in the 90's, sometimes over 100; it was always humid and about a third of the time it rained. (Perceptions of the climate differ. I remember one rainy day seeing Miguel Herrera come into our kitchen at lunchtime, shivering, to warm his hands over our kerosene stove. The temperature was 85 degrees.) The mud was so ubiquitous that the first part of my afternoon cleanup ritual was total immersion, clothes and all, in the ocean surf. Even I sometimes got chilly then.

I often laughed to think of what one "expert" on Latin America had told me when, as a student, I had asked why aquaculture was so poorly developed there when the need was so great and the climate so favorable. "Because the people don't like to work in the water", the great man said.

Far fewer snakes were seen after stump removal was completed, but one day a full-grown alligator cruised through, looking grouchy. If you want to feel helpless, try facing up to an alligator in the water, armed with just a shovel. There were mosquitoes, and a rather remarkable diversity of creatures capable of crawling up pant legs and biting. There was also the constant problem of infections resulting from scratches, machete cuts, mud in the eye, etc. Susan was kept busy dispensing aspirins, alcohol pads, bandages and eye drops. Feet, in particular, suffered; a vicious sort of rash affected nearly everybody. The thought that workers were literally limping five miles to work every day on sore feet was bad enough, but the sight when they removed their boots was appalling. Oddly, after the first couple of weeks, I was not affected. I habitually worked in ragged sneakers, while the others wore the loose-fitting calf height rubber boots which are, for some reason, traditional in the area. Eventually, some of the men began to assume that my immunity was not solely attributable to insanity, and started working barefoot. The result was somewhat more cuts and scratches, but a whole lot less infection.

I was never sure just how seriously to take things. One day Omar "Mato" Briones showed up for work clutching his shovel in one hand and his jaw in the other. He was suffering from a toothache, but it was all I could do to send him home. A few days later he was in the hospital in Limón. From what I am told, Mato was lucky to have survived the infection he had.

Susan wisely offered no objection to playing a traditional role in this case – tending the house and garden, cooking and administering medical aid. Most days the men brought their own lunches, but about one day a week she would lay out a feast for everybody, judiciously balanced between traditional local foods and her own multi-ethnic improvisational cuisine. Every morning we would observe a five minute break when she brought out something to drink. Except on the hottest days, almost everyone preferred hot herb teas to cold lemonade.

Our task would have been difficult in any event, but the total lack of roads, stores or machinery made it that much more so. Negotiations for a chain saw never quite bore fruit, so all log cutting was done with axes. Mud from the middle of the ponds had to be carried to the banks in tubs and buckets. When we had broken every expendable such container in the vicinity we continued with plastic feed sacks.

A particular problem was encountered in building the reproduction pond. Our design called for the ponds to be approximately 1½ meters deep at one end and ½ meter deep at the other, with perhaps ½ meter of "freeboard" on the dikes. This did not necessarily mean that we would have to dig that deep, since dikes could also be built of dry earth from nearby high ground if that proved more feasible. However, it was necessary to get down to hard clay and to make the bottoms smooth and level. This was not too difficult in the larger pond, which was constructed first, but there proved to be an inordinate amount of semi-liquid stuff in the upper pond. It was almost impossible to walk in; sometimes it would take several minutes just to pick up your foot, and then you'd have to go back for your shoe. But it didn't matter too much, since often all that was necessary was to plant yourself and let the goop flow at you. However, neither a shovel nor a leaky bucket is an ideal tool for removing a fifty-fifty mixture of soil and water. We got it done, but it took forever. The distance from the bottom of the reproduction pond to the top of the dike is now about eight feet.

The unanticipated amount of excavation presented us with yet another problem. The deeper we dug, the more fallen trees we discovered. Apparently these were trees which had been cut when the area was first converted to pasture. Being tropical hardwoods, most of them had scarcely begun to rot. In many cases, they were pinned into the mud by downward extending branches. For about three weeks there was always at least one man flailing away with an axe in a constant shower of muddy water. The pieces, up to three feet in diameter, had to be rolled out, a process which left more than one of us on his face in the mud.

A final complication was provided by the peculiarities of the local climate. It seems that, in Gandoca, swampy areas flood during the dry season and drain in the wet season. The reason is that the swamps drain directly into the sea. During relatively dry weather, the Caribbean is often stormy and large sand bars are built up at the mouths of swamps and small streams, so that water from light rains and from year-round streams accumulates. When the rains come with torrential force, the sea is often calm and a sufficient head of fresh water is built up to cut through the sand bars and drain the swamps. With our pond drainage system uncompleted, we were forced periodically, sometimes as often as twice a day, to leave the pond site, troop out to the beach and shovel a channel, perhaps four feet deep and fifty feet in length, through the sand bar.

I had to start back to the States on May 5. By that time it would have been clear to anyone viewing the site that we were making two ponds and an accompanying drainage system. But it was not clear that we would be able to finish before the rainy season. My fears that our work would be undone subsided in late May when Oscar wrote to say that the aquaculture facility was completed. The dikes are reinforced with horizontal pieces of bamboo running the full length of the sides and with vertical stakes of wild cane. They are planted with grass to retard erosion and melanga and camote to feed the fish. I wish I had a picture, but the combination of high humidity and salt spray devoured my camera.

Both ponds are drained by a rigid PVC plastic pipe which passes through the bottom of the dam and is connected, on the pond side, to a flexible hose. These are the only non-indigenous materials used in the system. This device, invented by the Paraguayan fish culturist Juan Pio Rivaldi and known as a Rivaldi Valve, represents perhaps the simplest way to effect partial or total drainage of a pond at will.

As of this writing (mid-October '77), the ponds have survived all rains, as well as a hurricane which passed through Gandoca (a rare occurrence). While they have

yet to be stocked with fish, they are already serving an educational function. Even before I left, we estimated that two-thirds of all the men, women and children in the community had passed by to see the project, ask questions and in some cases suggest a site for their own ponds.

Susan and I seized on this opportunity to do some informal polling. We discovered that we were not in error in thinking that, even though Gandoca fronts on the sea, the community stands in need of fish, particularly since our friend John Holder, who made most of his living fishing with hook and line, has moved. Most people said they had fish for dinner three or four times a year and the same for meat, but that they would eat fish "three meals a day" were it available.

We have also had visitors from neighboring communities, including the regional health and law enforcement officials. I was invited to speak to the school children in Mata Limón. Easter Week, when it is traditional for Costa Ricans to go to the beach and Gandoca's population triples, we received visitors from all over southeastern Costa Rica and northeastern Panama. During our absence, Oscar has been in charge of the station most of the time and has continued our informal extension work.

With construction completed, the next phase of the project was to provide Oscar with some practical experience in aquaculture prior to my return. Costa Rica's oldest fish culture station is run by El Proyecto de Diversificacion Agricola in Turrialba. At the time we began our project, Raul Bonilla was in charge of this station. Unlike most "tecnicos" Raul began from the bottom, cutting grass at the station with a machete, and learned as he went, until today I consider him one of the most capable people in aquaculture in Latin America. I introduced Oscar and Raul, and Raul agreed to take Oscar on for a couple of months, with his salary to be paid by NAISA, so that he could learn the skills necessary to operate a fish farm. All that was needed was for me to write a letter to the Junta Directiva Cantonal Agricola in Turrialba. "A formality", I was assured.

But, between the time I left Costa Rica and the time when Oscar was ready to leave for Turrialba, Raul transferred to another fish culture station at Veintiocho Millas. Oscar, who had been delayed by a few small things like the hurricane, went to Turrialba, found no Raul and got precious little information. Meanwhile, I was involved in an exchange of confusing letters (formalities?) with the bureaucracy in Turrialba.

Finally, I phoned Herbert Nanne in San José. While placing the call I had cause to ponder my own preference for field work over office work. I had never met Sr. Nanne, only because I was too anxious to get into the field and get my feet wet to take time "going through channels." If I had been more willing to spend a few days tramping the streets of San José, would this problem have been averted? Was my taste for the field rather than the office a matter of wanting to get the "real" work done or just a personal environmental preference? Was I suited to administer anything? Would we ever get Oscar straightened out and fish in our ponds?

Sr. Nanne was most cooperative, but my call really wasn't necessary. In the meantime, Oscar had been to Veintiocho Millas and found, not only Raul, but also Herbert Nanne. Sr. Nanne was kind enough and impressed enough to put him to work immediately and to provide him with salary and housing through the Ministry. We have the feeling that it is still pretty unusual for an honest-to-God campesino to walk out of the woods into a government station looking for training in fish culture.

As I write, Oscar has just completed his training and is ready to take tilapia breeders back to Gandoca. The short-range plan is to stock only the reproduction pond. By the time I return in January, there should be enough good-sized young fish to sex them and stock males only in the growing pond. We will feed the fish much as Patiño did, but we will sex our fish rather than use cages to prevent unwanted reproduction, as we know of no locally available cage material comparable to the Colombian "guadua" bamboo. A possible experiment for the coming year involves the cultivation of termite nests, found on dead wood everywhere in the region, as a protein source for tilapia. In years to come we hope to plug various native fishes into the system but we wanted to begin, not with an experiment, but with a fish people know how to cultivate.

The eventual course of fish culture in Gandoca and Mata Limón, and particularly its economic application, will have to be decided by the community. This year we plan to adapt techniques to the local situation, demonstrate tilapia culture, and produce as many young fish as possible. We will also consult with local farmers on the siting and construction of ponds and provide training in fish culture for others in the community, Llunier particularly.

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My narrative has concerned aquaculture almost exclusively, but that is not our only activity and much less do we envision it as such in the future. In the fourth *Journal*, I described our work with the herb tea plant known as soril. During 1977, Susan was largely responsible for continuation of our soril research. At this point, we can say that we see no particular problems in soril agriculture, though I'm told it doesn't stand up well to hurricanes. So far, we have not found processing methods suitable for use by small farmers on the scale we envision. Our failure to do so can be explained at least partly on the basis of my own lack of diligence in searching out appropriate technology for the task. That can in turn be explained by my preoccupation with aquacultural and administrative questions, and also by the fact that the soril growers of the community and I are questioning the appropriateness of the crop for the area.

We do not question the need for some sort of cash crop. I have explored the need for cash crops in *Journal Four*, but we are beginning to suspect that the advantage in producing export crops like herb teas lies with the giant corporate farm – and that is just what we do not want the region to turn into. Perhaps it would make more sense to use fish or fruits, which can contribute needed food directly to the community as well.

One important finding with regard to soril came from the kitchen. Susan proved that it can be made into delicious pies and jams. The locals, accustomed to using it only for teas and cold drinks, were quite impressed by this. Perhaps some day soril will play a substantial nutritional role.

Whatever happens, soril has already played one important role by serving as the basis for our first community experiment. Soril provided the first opportunity for the farmers of Gandoca and Mata Limón to work together with NAISA people, and for all of us to iron out some of the doubts we might have had about each other. From that point of view, there can be no such thing as a "failed" project.

Crafts are anything but highly developed in the region. Susan's vegetable dyeing and weaving attracted much interest and even some offers to buy. This year she will be taking on one weaving student, Filomena Vargas.

We also discovered another important function for ourselves this year as intermediaries between the community and the world of aid and development. Seeking funding to complete the fish culture project,

we made contact with John and Mary Contier of Catholic Relief Services in San José and invited them to spend a few days at the farm. During this time we arranged a meeting, which deliberately was kept small. Oscar and Llunier were invited to speak for the fish culture project and Matute as representative of the community-at-large.

However, another friend, perhaps misconstruing the purpose of the gathering, also showed up, roaring drunk on rubbing alcohol – with his radio. "Merican music! Plenty swing!" My evening amounted to a wrestling match as I tried to moderate the radio, dissuade our friend from offering his poison to the others and reason (?) with him. To add to the hilarity, Oscar with his machete slew a rat that dashed across the kitchen floor. It was certainly the most irregular meeting in the annals of New Alchemy (not an organization noted for excessive formality), and for all practical purposes I missed it. I didn't much care. I figured our friend had blown whatever chance we had of getting help.

To my amazement, when the smoke of battle cleared, I discovered that the Contiers had offered, not only to try to help fund the fish culture project, but to look for support for a larger community development project for Gandoca and Mata Limón. However that came about, it was not on the strength of what *I* said at that meeting.

I tell this story, not just because it is amusing or for the sake of conveying the news, but because it points up one of our legitimate roles in Costa Rica. There are any number of organizations like Catholic Relief Services in countries like Costa Rica, staffed by good people like the Contiers, who are looking for good projects. There are, in the rural communities, any number of hard-working and concerned people capable of articulating their needs if given a forum. And seldom the twain do meet. If a person from one of the agencies does get out into the country, it is a hit or miss proposition whether he or she will get to the right community and meet the right person. If the campesino goes to town he is often ill prepared to find the right door to knock on and, if he does get in the door, he is liable to be brushed off by the receptionist. In retrospect, we may eventually decide that the two most vital tasks we performed in Costa Rica in 1977 were to bring the Contiers to Gandoca and to put Oscar in touch with Costa Rican aquaculture officials.

The CRS meeting was followed by one of the community Junta Directiva (plus a few), also held at our house. This meeting, which commenced with a tour of the fish ponds, was attended by Aquiles Rodriguez, Lino Ramon Lopez, Ismail Rojas, Victor Briones, Juan Centeno, Lauriano Duartes, Orlando Sequiera, Matute, Oscar, Susan and myself. It was as orderly as the preceding one had been riotous. We were pleased to see all ages represented on the Junta, though we would have been more pleased to see some women present, as women do participate in community meetings.

A long range plan of development for the community was presented, which included such items as a dispensary, a community hall, improvement of foot roads, an airstrip and purchase of a launch to get goods in and out. One might have expected a community having their first brush with the funding world to excitedly bite off more than they could chew. Instead, they decided to ask for far less money than the maximum which the Contiers indicated might be obtainable and to limit themselves to two projects, since more projects undertaken could lead to projects badly done. They chose our underfunded aquaculture project, since that was already under way, and the launch, since that seemed to have the least chance of ever being realized without outside help.

I was dispatched to San José "in total trust" to draft a proposal describing the community's resources and needs and explaining the two projects. As of this writing, the proposal has cleared the CRS and Church authorities in Costa Rica and is under consideration in the New York office of CRS.

One other important item of business was accomplished in 1977; reorganization of the Board of Directors of NAISA. Our original board, apart from myself, were "paper tigers" who lent their signatures to help legitimize our activities in Costa Rica. As of this spring, I am the "secretario", Matute is "tesorero", Robert Wells is "fiscal", and Margarita Downey Saborio is "presidente." Bob (an attorney) deserves special thanks for giving us a lot of "informal" (= free) legal advice in times of real poverty.

Our plans for the future are largely contingent on funding. Fortunately, we are enough of a campesino organization that we will be able to do something under any economic circumstances. But we do have plans and dreams. They are rooted in the opinion, held in common by ourselves and all the farmers we have talked to in Gandoca and Mata Limón, that far, far too much of the agricultural (and aquacultural) research being done benefits only the large grower. This is partly a reflection of how research funding is directed but, especially in Latin America, it also reflects a lack of awareness by scientists of the realities faced by the small farmer.

Elsewhere in this *Journal* I have mentioned the idea of a research institute directly responsive and responsible to the campesino. The groundwork for such an institution has been laid by NAISA and the people of Gandoca and Mata Limón. Another step was taken when Tom Gardiner, a young man with Peace Corps experience in Costa Rica and an M. S. degree in agriculture from the University of Massachusetts, signed on for six or eight months with us. If all goes well, he will extend that stay and begin to design and carry out agricultural experiments in collaboration with local campesinos.

Before this plan progresses very far we will need to have a real farm and a building or two. (The present NAISA "farm" is really no more than a plot of land to live on and grow a few vegetables.) Nothing elaborate – it is a tenet of NAISA that workers from outside should live in and as the community – but it does take land. In the short run, I am sure we can do research on our neighbors' farms, but in the long run it is neither convenient nor fair to tie up other people's land in lengthy experiments. We will never be a large group; too large an "outside" presence would inevitably be disruptive. But we do hope someday to have facilities for guest and student investigators.

Our present needs are for land, funds – and a skilled translator to help us make our work available in Latin America outside our immediate area. We do not, and probably never will have, an "office staff", but serious inquiries are invited. You may write to this address or to Aptdo. 902, Puerto Limón, Costa Rica.

VISITORS – COSTA RICA

We are beginning to receive a substantial number of letters asking to visit the NAISA center in Costa Rica. More surprising to us – in view of the sixteen mile hike ordinarily necessary to reach us – during the first four months of 1978 we received several drop-in visitors. Nice folks – mostly – but it *is* inconvenient when you're cooking for dinner for three and suddenly there's six.

So – it always comes to this – we are going to have to inaugurate A POLICY. The policy will be different from the one we have on Cape Cod. Most readers are familiar with "Farm Saturday", which permits us to accommodate the public one day a week, while still getting on with our other work. Such a program is not feasible in Costa Rica for the simple reason that, located as we are, any visit is perforce at least an overnight visit. And there are *no* overnight accommodations remotely near us.

It is probably appropriate to say something about the difference between our overall program in the United States and Costa Rica. In the States we function primarily as a research institution, developing ideas and techniques for dissemination outside Hatchville. In Gandoca we do some of the same, but we are more concerned with approaches to community development as they can be implemented in our community. Thus, there are less interesting gizmos to look at and a greater need to deal with *local* drop-in visitors. We feel that it is essential that we be open to residents of Gandoca, Mata Limón and neighboring communities at any time, and a considerable part of our time is consumed in dealing with such visitors. So we must ask that other visitors have *very specific reasons* for coming. There are simply not enough of us to have it otherwise.

If, after careful consideration, you really feel that you have something important to learn from us or offer us, we insist on the following:

1. Secure permission and set a date ahead of time. This can be done by contacting Bill McLarney at the Cape (June-December only) or by writing NAISA, Apartado 902, Puerto Limón, Costa Rica. Allow plenty of time for letters to Costa Rica; as much as a month may pass between visits to our mailbox.

2. Be prepared to work hard at whatever you are asked to do.

3. Be prepared to be completely self-sufficient with respect to shelter and food. We *may* be able to offer a roof or share food, but we can't promise.

4. Be aware – as some travelers are not – that anything you'd think twice before doing in North America bears at least three thoughts in Costa Rica. I am thinking particularly, though not exclusively, of drugs. Any substance that is illegal in North America is more so in Costa Rica. It is a *rule* at NAISA that *no* illegal substance is brought in or through the property, bought, sold, used or planted by anyone. Any infraction of the laws would implicate us all, and we cannot take *your* risks.

5. A good command of Spanish is very helpful, though not absolutely essential.

We trust that you will understand our situation and that this policy will not cause too much inconvenience. We will continue to publish on our experiences in Costa Rica (hopefully, soon in Spanish) and hope that this will fulfill much of our responsibility to communicate.

Book Reviews

– Nancy Jack Todd

There were two books published during 1977 that I should like to review for readers of the *Journal* who might not yet have encountered them. Both are by women and, although they are very different, I think they are both important books. Their writing could be looked on as an act of service. In the case of one of them, *The Underside of History,* it is a comprehensive attempt to revision history and to write in the role of women, so that not only women, but all of us might gain a more complete sense of the patterns and events that have led us to the present. The other, *Creating Alternative Futures,* begins with the present, analyzes how we managed to get into our current economic and resultant ecological debacle, and suggests practical stratagems for making the transition to a sustainable future.

Photo by Hilde Maingay

Boulding, Elise. 1977. *The Underside of History, A View of Women Through Time.* Westview Press, Boulder, Colorado. 829 pp.

During most of the Vietnamese war, I lived in Ann Arbor, Michigan. I worked there with a very impressive group of women who called themselves, collectively, "Ann Arbor Women for Peace." They were affiliated although not actually a part of the national "Women's Strike for Peace." It was working with this group that first led me to believe in the untapped potential in greater participation by women in public life. One of the activities that involved a lot of our time was the collating, folding and stamping of the seemingly endless streams of mail that issued from and through us. In the talk that accompanied our moving hands, a name that recurred often was that of Elise Boulding – Elise speaking here – meeting with influential people there. We knew her as a Quaker and a pacifist. She was, for us, a model, a woman with the courage of her convictions, deeply committed to, and active in the attempt to end that senseless war.

Now she has written a book out of her dedication to another cause important to her: that of righting the imbalanced perception we hold of the roles played by women throughout the past. Initially, when I first decided to review the book for *Journal* readers, my thought was to recommend that every woman should have a copy for herself and for her daughters, if she had them, but that, of course, is wrong, for men suffer as much as we do from the distorted view of history and stand to benefit as much from a broader understanding of the evolution of the human family– and not just of mankind.

Dr. Boulding's book is entitled *The Underside of History, A View of Women Through Time,* and is dedicated to "all women of every time and space who are this book." The book is a retracing of the past onto which she lovingly draws in bolder strokes the shadowy figures of the women whose lives, over vast reaches of time, precede our own. The early chapters are devoted to our evolutionary heritage and cover sexual dimorphism and dominance and the development of sex roles. Turning to the paleolithic and building on a thorough researching of archeological clues, Dr. Boulding reconstructs the ways in which women lived in hunting and gathering bands. With the beginnings of agriculture and the establishment of patterns of settlement came changes which magnified as the scale of settlement grew from village to town to city. Work became specialized and civilization, as such, began. The great ancient civilizations in Sumer, Egypt, India and China are discussed.

One of the most interesting aspects of the book for me, as a former history major, lay in reading about the cultures to which I had had considerable exposure and in discovering how completely the quality of the lives of women had been glossed over. For example, roles of women in Ancient Athens are portrayed as richer and more varied than the cloistered, domestic ones of which I had read. Dr. Boulding points to the painting, sculpture and tragedy of fifth century Athens as indicating the psychic force women must have had in spite of being political nonentities.

Similarly, in the description of European history, which I had studied in some detail, I discovered so much I had never known. Of kings we heard much, but never of the young princesses, trained from early childhood for political marriages on which the fate of nations often depended. While still in their teens, many of these young women kept peace between otherwise fractious countries through embodying family alliances that straddled conflicting political ambitions. It was said that, for a king, every daughter was worth a standing army if deployed in the right way. Dr. Boulding tells of the devotion of many Eastern European queens, princesses and noblewomen in caring for the sick and the poor. And there are wonderful human stories of such well-known figures as Eleanor of Aquitaine whose last signature on a public document read, "Eleanor, by the wrath of God, Queen of England." For the first time, I learned of the Beguines, a lay sisterhood that provided a place for working women, both physically and socially, as an alternative to marriage or the church. The slightly better-known work of religious women, mystics and nuns is also discussed.

For a book that is eight hundred and twenty-nine pages long, scholarly and covers a time-span from the paleolithic to the present, any attempt at description can only be random sampling and, as such, completely inadequate. It is thoroughly documented with references, charts, tables and figures and is illustrated with photographs and reproductions of drawings or illuminations. One such is from an illumination from a medieval manuscript and depicts with delicious irony a nun and monk tilting, the nun with evident and malicious enjoyment going at the disconcerted monk. Others portray some of the moments and range of joy and pain and work that women have experienced.

It is a book one wants within reach for a lifetime, to turn to again and again. It begins to address an enormous gap in the human sense of self. Dr. Boulding says, "The idea that great women are as evanescent in history as the melting snow is a poetic statement of the fact that women are invisible to each other, as well as to men, as the makers of history. They do not know their own foremothers."

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Henderson, Hazel. 1978. *Creating Alternative Futures.* Berkeley Publishing Corp., 200 Madison Ave., N. Y. C. 403 pp.

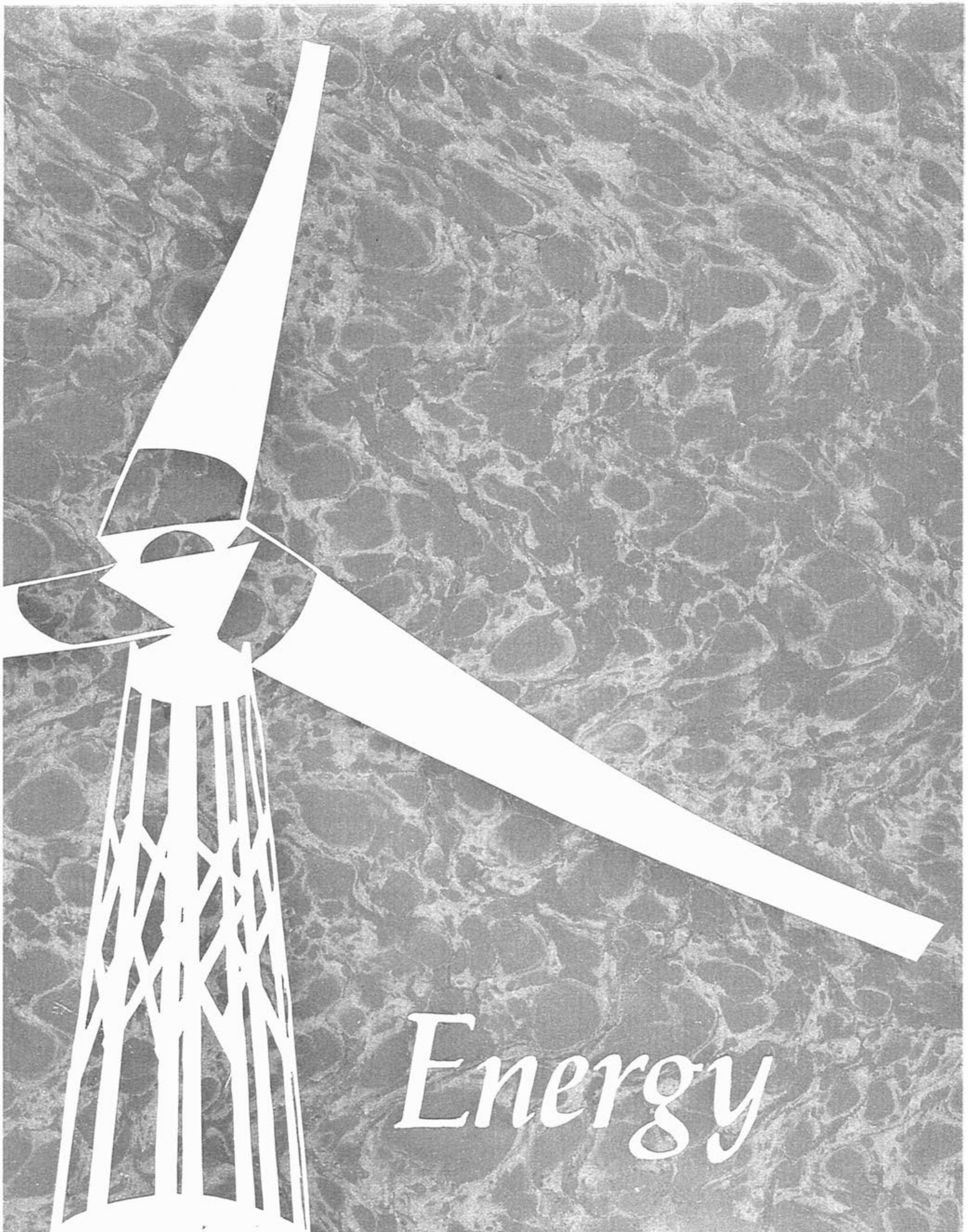
Creating Alternative Futures is a collection of Hazel Henderson's essays and talks over the last eight years, although the majority are from the last three. Hazel Henderson is an innovative thinker. With Carter Henderson, she is the founder and co-director of the Princeton Center for Alternative Futures, Inc., an entity which William Irwin Thompson has referred to as "a Mom and Pop think tank." Her book, which is subtitled *The End of Economics,* begins with an overview of the current state of society which she calls "Recycling Our Culture." In it, she describes the cultural climate of confusing apparent anomalies in which experts from various disciplines issue conflicting statements on the state of public affairs and how those of officialdom – government, the military and industry – often belie the experience and observations of the individual. She points out that bureaucracies, by dint of their structure and size, are inherently resistant to change, leaving an inevitable time lag between attitudinal changes in society, even when they are quite widespread, and changes in public policy. That the linear, Cartesian, reductionist paradigm is long bankrupt and no longer has survival value is becoming increasingly accepted, as is the need for a paradigm shift, yet it is not reflected in the activities of government or business. Ms. Henderson suggests the image of the hologram, an information system in which every bit contains the program of the whole in much the same way as New Alchemists use the biological metaphor, to conceptualize a decentralized, communitarian society based on a humane, organic technology.

The first half of the book is comprised of an analysis of the "end of economics." For those who have accepted a world-view that admits to the folly of the continuing espousal of ongoing industrial growth in a world of finite resources, expanding population, mounting social dislocation and environmental degradation, this section of the book will serve to clarify understanding as to how we have reached this pass. For people who have succumbed to an uneasy feeling that all is not well, but are not sure where to turn for guidance, it should come as something of a revelation and as reassurance that they are not mad after all. The emperor is bare, indeed. And for those still clinging to Keynesian economic theory, I can only speculate that they will find a cogent debate that they must respect as containing arguments and evidence they will be hard-pressed to deny or brush under the carpet.

The second half of the book is devoted to the paths we might follow in creating a sustainable future. Many of the ideas will be, in some degree, familiar to people with an acquaintance with the counterculture or any of the wide range of alternatives that sprung up over the last few years, yet they are seen with such clarity and a wholistic and kindly vision that disparate efforts can be seen to be merging into a discernible pattern, reaching both horizontally and vertically into society. At the governmental level, the Office of Technology Assessment provides a channel through which the Congress can hear from less established constituents. She lists the Council for Economic Priorities, the focus of which is vigilance for malpractice in industry and government, consumer organizations like Consumer Action Now and environmental concerns like Friends of the Earth, as well as the less well-known activities of groups like block committees as epicenters for participatory social transformation. It was such a collective melange that was responsible for the first Earth Day and, more recently, Sun Day.

Ms. Henderson advocates the imaginative use of the media as a means of democratizing the creation of policy by giving civic and public service groups access to the public. As she points out, freedom of speech and of the press are hollow privileges in an electronic age, if you can reach no one. The diverse roles played by agents of social change are described, from feminist and ecological groups through professional ones like the Union of Concerned Scientists, as well as Alternative Technology organizations and the functioning of informal networks for the exchange of information and encouragement.

In a lovely image in the epilogue, Ms. Henderson says, "It is said that Minerva's owl only flies at dusk, and we only see the age in which we live at its twilight." She has helped us to do so with this humane and intelligent book.


Energy

If the section on energy for the fourth Journal was a bit thin, registering only our on-going and unalterable opposition to nuclear power and offering no word of our own work, it was because a report of our recent windmill work was, at that time, premature. Happily, that is not the case this year. Having found a reliable pump made from a trailer tire that is geared to the capacity of our water-pumping sailwing on Cape Cod, we feel that we have developed a water-pumping or irrigation system that is worthy of replication and adaptation. The New Alchemy Sailwing is the subject of the windmill article by Earle Barnhart and Gary Hirshberg and was first published in Wind Power Digest for the winter of 1977/78. It summarizes the evolution of the mill over the four years from its inception to its present form. One notable windmill-ish fact that Earle and Gary do not mention in their sketch of windmill history is that England's Domesday Book of 1086 documents five thousand mills, one for every fifty households. There is something rather nice about being part of the renewal of a technology that has served people well before, a sense of commonality with the past, perhaps.

The companion article to that by Earle and Gary is by Tyrone Cashman and describes the mill that he built for the Zen community at Green Gulch in California, using the New Alchemy sailwing as a prototype. In addition to the background and the actual construction of the Green Gulch sailwing, he discusses the modifications he made to adapt to conditions very different to those on the Cape. This is interesting for us as New Alchemists because, like Meredith Olsen's in the Aquaculture Section, it is the first documented feedback we have had on a second generation of the application of our ideas and, as such, it opens wider channels for comparison and critique.

The final article in this year's Energy trilogy is by Joe Seale who has spent the last year working with the HYDROWIND, the electricity-generating, hydraulically-operated mill that New Alchemy has developed on Prince Edward Island in Canada. Joe, who has since joined us on Cape Cod, explains the pros and cons of HYDROWIND I after a year's study and testing. He discusses the machine in some detail and evaluates not only this particular mill but various theoretical approaches to aspects of windmill design. He sees a need to make available in writing a body of knowledge that has been until now largely oral and, as such, scattered and lacking in organization. — *NJT*

Photo by Hilde Maingay

The New Alchemy Sailwing

– *Earle Barnhart and*
Gary Hirshberg

Over the past several years we have been investigating the applications of wind-powered water-pumping systems. We have been particularly interested in sailwing windmills which generally can be constructed of indigenous materials with limited equipment by people who are not trained specialists. In contrast to more sophisticated designs, sailwings can be adapted to places poor in resources such as rural areas or third world countries. Windmills have been used for irrigation for more than twelve centuries in areas where cultivation would be otherwise unfeasible.

At New Alchemy on Cape Cod we needed a water-pumping system for aquaculture projects and to irrigate the gardens. We wanted to design a windmill that could be constructed by a do-it-yourselfer using local and/or available materials. It was important that our water-pumping system be simple and inexpensive, require very little maintenance and be storm-resistant. The windmill had to be adjustable for varying wind speeds and wind directions. It was essential that it be operative in areas of low wind speeds for it to be broadly practicable.

Four years of experimentation and research, beginning with Marcus Sherman's bamboo/cotton sailwing windmill in Southern India, have culminated in the design and construction of the New Alchemy Sailwing which meets these objectives. Familiarly known as "Big Red" (Figure 1), it was named for its first set of bright red sails. It pumps in winds as low as 6 miles per hour and in gales of up to approximately 40 mph. Although our water-pumping needs do not extend into the winter, the Sailwing is operable throughout the year. People with year-round demands need only take normal cold weather precautions against pump or water-pipe freezing damage.

Sailwing Description

On top of the 26-foot wooden lattice tower, a horizontal axle leads to the junction of three steel masts (Figure 2). The multi-colored Dacron(R) sails are attached to the masts by grommets and pegs, like the rigging of a sailboat. Elastic shock cords connected to the adjacent mast pull the sail root out to form a smooth surface for catching the wind. The shock cords allow for self-feathering and easy furling in storm conditions. The sail tips are attached to fixed triangular pieces at the ends of each mast.

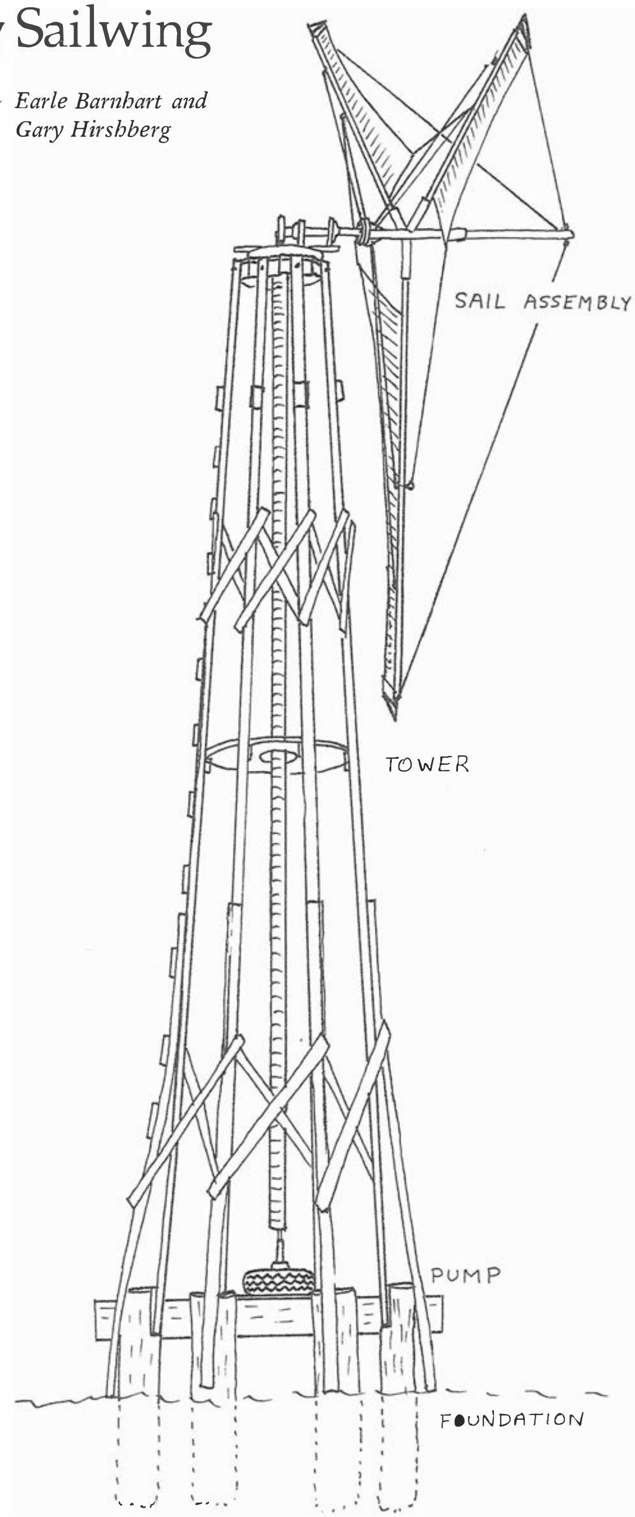


Fig. 1

All drawings by Earle Barnhart

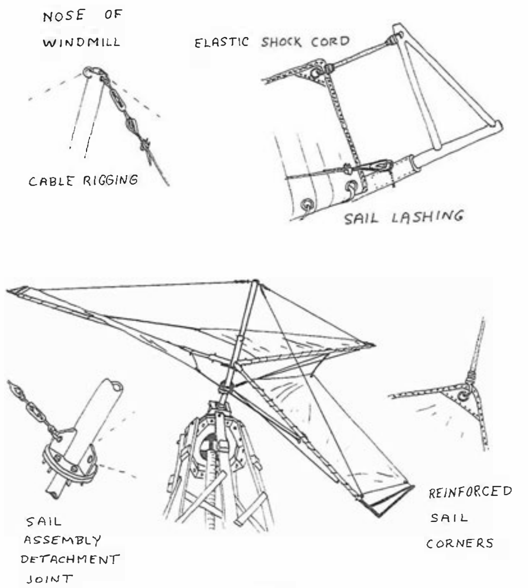


Fig. 2

The axle and sails are oriented downwind from the tower, eliminating the need for a tail. Wind power is transferred along the rotating axle through a pair of sealed commercial bearings (Figure 3). A steel disc crankshaft mounted at the base of the axle transfers the axle rotation to the vertical motion of the pump shaft. Five distinct stroke settings are provided by holes drilled at different radii from the disc center. The assembly is centered on a steel plate turntable above the tower. The adjustable stroke disc is centered directly above a hole in the turntable through

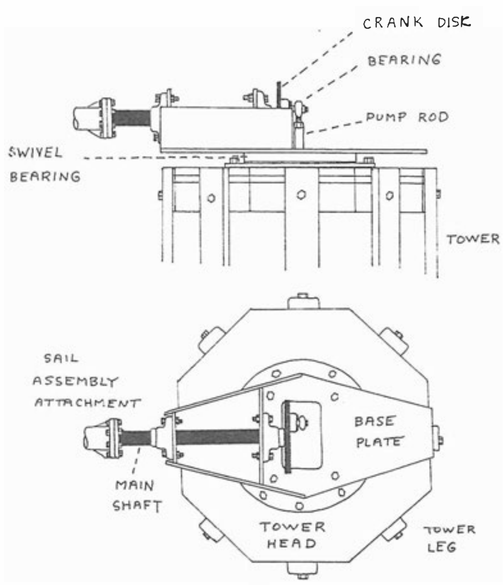


Fig. 3

which passes the pump shaft. From the disc, power is carried down the tower along a three-inch diameter shaft to a diaphragm tire pump at ground level (Figures 4 and 5).

The windmill tower is made of eight 2 x 4 legs bolted to buried sections of telephone pole. Curved wooden buttresses add support at the base and two sets of latticework give additional stability above. A secondary platform rests approximately halfway up the tower.

Origins of the Sailwing Windmill.

A brief look at windmill history indicates that the New Alchemy Sailwing is a scion of considerable heritage. The origins of windmills are somewhat obscure, but primitive horizontal mills are thought to have been employed in seventh century Persia. Legends recount that prisoners of the Genghis Khan carried the idea of wind-powered grinding and water-pumping mills to coastal China. There, horizontal mills with matted sails came into use. These primitive mills became obsolete by the end of the twelfth century as the application of Chinese sail-making increased the sophistication of windmill construction. The sailwing had an unparalleled maintenance-free life-span due to its durability and simple, lightweight design. It gained widespread application throughout coastal China. The same criteria explain the ubiquitous employment of sailwings in China and Southern Asia today.

The European windmill developed independently of its Asian counterpart. The first documented mill was used for grinding grains in England during the latter part of the twelfth century. By the seventeenth century, due largely to the extensive exploitation of wind both on land and sea, the Netherlands had become one of the wealthiest nations in the world. Cloth was the commonly-used material for windmill sails during this period, reflecting its application on sailing ships. Among the advantages of cloth were light weight, ease in handling, low cost and availability. Most importantly, when supported at three or more points, cloth forms a strong uniform surface for catching the wind.

These advantages hold true today, as is evidenced by the widespread use of cloth for windmill sails. Currently, handcrafted sailwings are employed in Crete, India, Ethiopia, China and Thailand, among others. Researchers at Princeton recently have developed a two-bladed high-speed aerodynamic Dacron(R) sailwing for use in the United States.

1973:

Marcus Sherman and Earle Barnhart first experimented with sailwings at New Alchemy in the summer of 1973. They devised a three-bladed wood/canvas sail propeller which was used for driving pumps and power tools. Although this model was destroyed by a January ice storm, Marcus was encouraged by the simplicity and efficiency of the sailwing concept.

1973-1974:

In Southern India that winter, Marcus built his first water-pumping sailwing windmill. There local farmers were experiencing hardship induced by the vagaries of monsoon-related droughts and flooding. Inadequate and costly power sources made reliable irrigation difficult. There was, however, a large untapped supply of groundwater. This prompted Marcus to consider harnessing the wind for irrigation on the farm of a friend. To complete the irrigation system, scientists at the Indian Institute of Agricultural Research in New Delhi recommended a modified paternoster pump, like that used to drain the mines in Britain in the late sixteenth century, because of its simplicity and low-cost construction. Chain pumps such as this work well with the relatively slow and variable power that is characteristic of windmills.

Marcus developed a mill that was a hybrid of the low-speed, eight-bladed Cretan sailwing and the high-speed aerodynamically-efficient Princeton model — "A Windmill in India", the second *Journal.* Using a bullock cartwheel roughly one meter in diameter as the hub, he attached to it triangular sailwing frames made of bamboo and nylon. A cloth sail was stretched over the frame to produce a stable, lightweight airfoil. The rotor assembly was attached to a used automobile axle. Marcus made a turntable from ball bearings sandwiched between two doughnut-shaped discs. The axle was mounted horizontally on top of the turntable. A rudimentary "squirrel cage" assembly for housing the drive chain and gasket pump was centered on the axle directly above the one-foot-diameter hole in the turntable.

The sailwing was headed downwind to prevent the bamboo poles from bending and striking the teak pole tower in monsoon winds. In this way the blades served as their own tail, trailing in the wind. In the process of the subsequent well digging, the mill was used with a pulley assembly to raise soil and rock from the 20-foot-deep well. Because of its high starting torque at low wind speeds, the mill proved well suited for year-round irrigation in Southern India.

1974:

Back at New Alchemy the following summer, Marcus, with Earle, gave the sailwing concept another try. With lumber and hardware, they built a durable prototype well able to withstand the often blustery Cape Cod climate. For a total material cost of $300, they developed an 18-foot-diameter, cloth sailwing capable of pumping 250 gallons per hour in 6 mph winds. Three tapered cloth sails, supported by tubular steel masts, extended from a triangular plywood hub. A moveable boom was secured at the

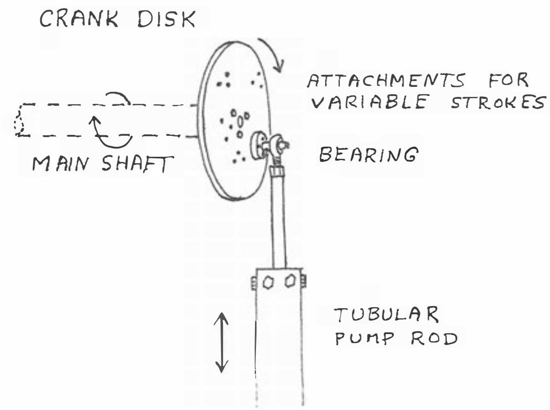


Fig. 4

root of each sail by a leather strap to further self-feathering. Long metal doorsprings connected each of the three sail booms. In early tests, the feathering mechanism withstood a force-nine gale.

A used automobile crankshaft formed the hub and crank. The assembly turned on a ball-bearing turntable which allowed the windmill to seek a downwind operating position. A recycled piston rod on the crankshaft transferred power to a reciprocating vertical steel pipe pump shaft. The shaft operated a high capacity piston-type pump below. The entire struc-

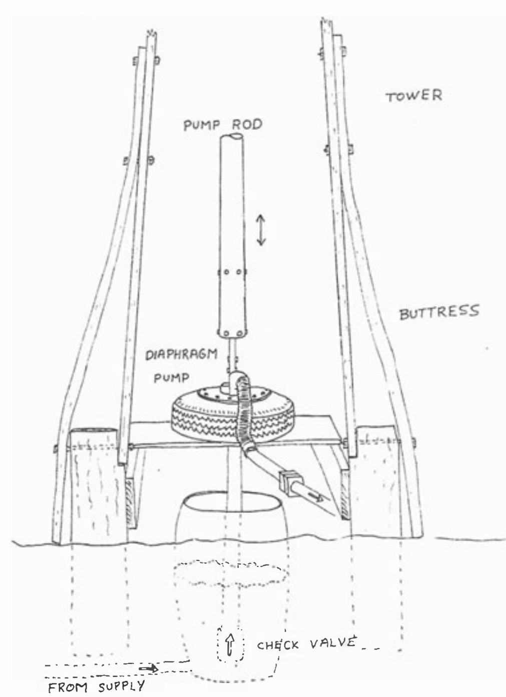
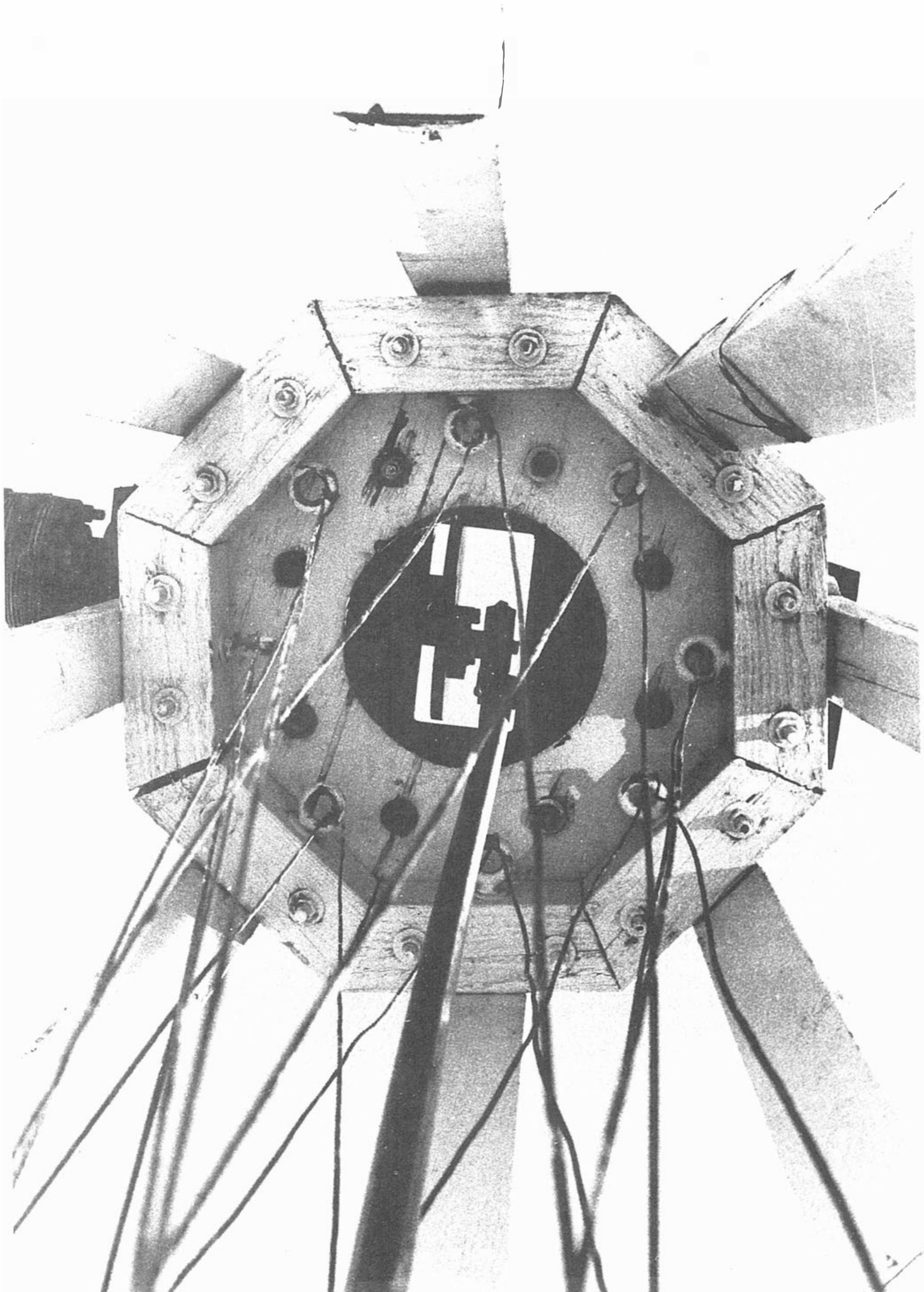


Fig. 5



ture was mounted on a firmly-braced eight-legged wooden tower.

The windmill supplied water to a series of twenty small ponds used in our midge experiments. It was operational in high winds, although the cloth sails were removed in severe storm conditions. The cotton sails were later replaced by Dacron (R), which is longer-lived, holds its shape better, does not absorb water during rains and is stronger and lighter than cotton. On preliminary testing, Marcus found the performance of the mill to be significantly lower than its calculated pumping capacity. A double pump was used. This and subsequent models employed downwind sailwing blades which minimize the chances of the sails tangling in the tower while feathering and eliminate the costs of a large tail.

1975-1976:

The current model was built in 1975 and incorporates many of the features of its prototypes. Several new ideas were tried. An extension shaft was added to position the hubs and blades further from the tower. We had noticed that the slip-on sock-like sails frayed where they were wrapped around the blade shaft. Traditional sail makers advised us to attach the sails with grommets and pegs and to position a stabilizing cable from wing tip to hub to prevent flexing of the blades. In addition, we added a simple spring-feathering device to each of the sailwing tips.

The double pumps used previously with the prototype proved undersized for the strength of the new model, so a higher capacity and more compact diaphragm pump was tried. Tests were also carried out with a deep wooden piston pump like a marine bilge pump, but the diaphragm was more reliable.

The auto crankshaft that made up the hub and crank on the prototype was found to yield too small a stroke for the mill, so Mac Sloan, an engineer who advises us on windmill problems, devised an ingenious disc-bearing assembly to drive the pump (Figure 3). The disc/bearing assembly functions as a crank with a variable pumping stroke. Sealed commercial bearings were added to the windmill shaft at this time, as the original homemade bearings wore too quickly and demanded frequent lubrication. Curved buttresses were attached to the tower legs to support the additional weight of the crankshaft, extension and other hardware which had been added subsequent to the original design.

1976-1977:

Several other features have been improved since the spring of 1976. Strong elastic shock cords have replaced the door springs used for self-feathering, resulting in increased flexibility and smoother sail motion. The shock cords are easier to maintain and preclude the need for a boom.

Mac Sloan helped with another part of the present sailwing system. He designed a smaller diaphragm pump, adjusted to the mill's one-gallon-per-stroke capacity. Once the pump was able to handle the mill's power, the pump shaft became the weak link. Excessive flexing in the half-inch pipe shaft led us to replace it with a rigid three-inch EMT shaft.

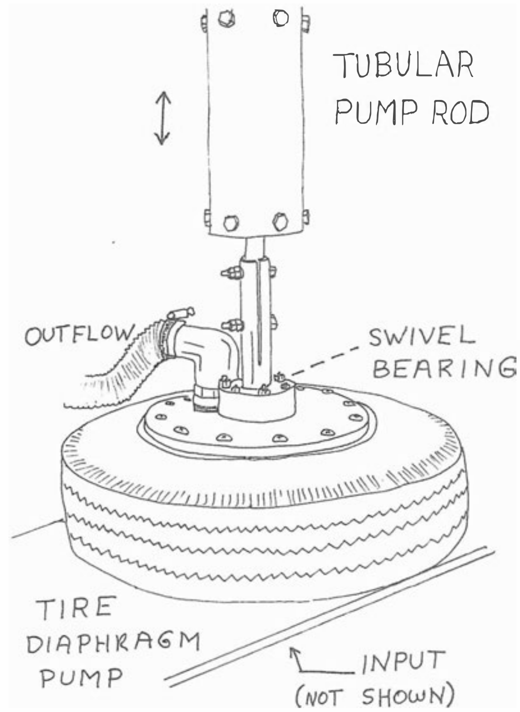


Fig. 6

Operation and Maintenance.

Self-feathering: In normal winds (0-15 mph) the taut sails catch the wind and drive the pump. In higher winds (15-30 mph), increased forces on the sail press downwind, stretching the elastic shock cord and allowing some of the wind to spill past the sail. This automatic feathering results in continuous pumping in higher winds without destruction of the blades.

Reefing: During very high winds and gales (> 30 mph) we protect the windmill by reefing the sails. The blades are stopped by hand from the mid-tower platform and each elastic cord is unhooked from its metal mast attachment. Each sail is wrapped around its own mast pole several times and then bound by winding the cord around the sail and hooking it. This arrangement leaves only a small triangle of sail exposed at the outer end of each mast, which in high winds is often enough to continue pumping.

Adjustments: Several adjustments can be made to adapt the windmill to different average winds or pumping requirements:

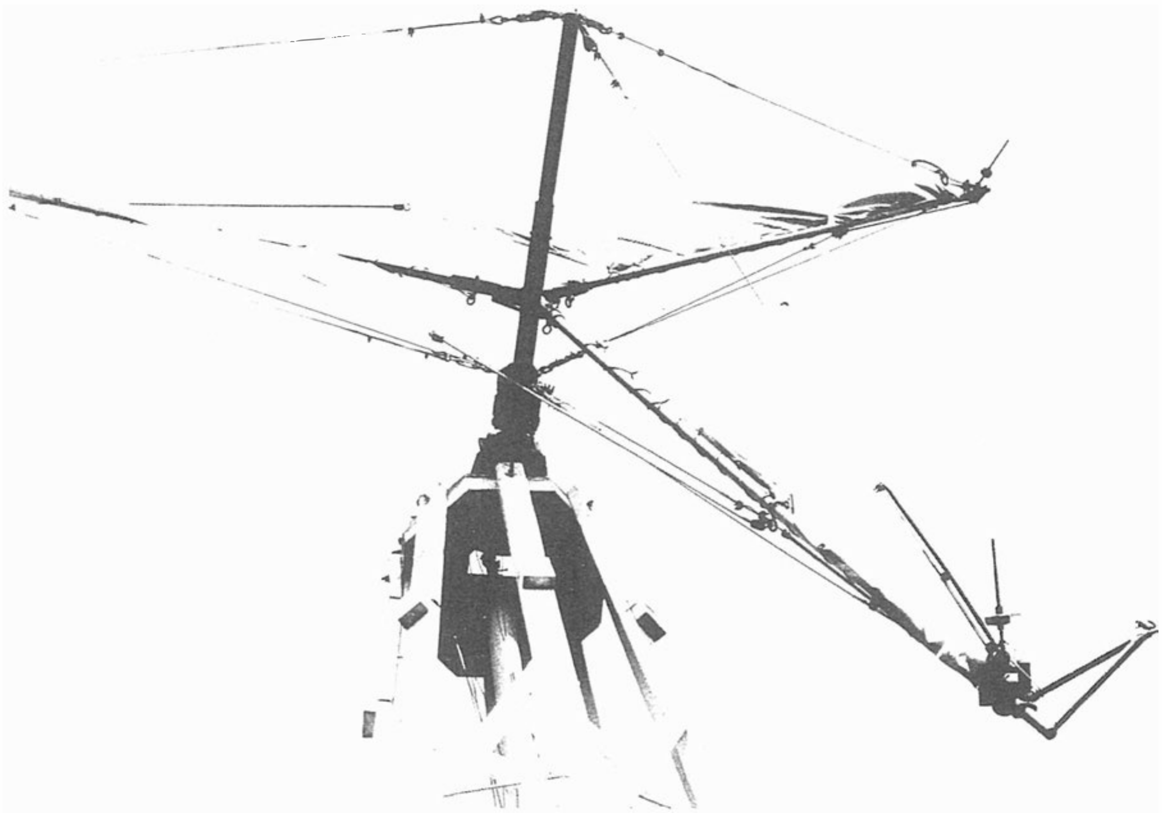


Photo by Hilde Maingay

The Pump Stroke - The pump stroke of the windmill has five settings depending on the attachment point of the pump rod to the crank disc. In a given wind, the windmill can perform a fixed amount of pumping work which can take the form of a low lift of high volume or a high lift of low volume. Our winds average 8-9 mph in summer and our need is to pump the largest volume possible to a height of four feet. Our custom-made diaphragm pump lifts .875 gallons per two-inch stroke in average winds. In high winds we have measured 700-800 gallons per hour.

Combinations of stroke-length, pump volume and height of lift must be developed for each application and site. Sailwing windmills such as this one have been used with piston pumps for 20-foot lifts/ 10-foot heads and with chain and trough pumps in Southeast Asia for low-lift irrigation.

Shock Cord Tension - The response of the windmill to varying winds depends on the tension of the elastic shock cord holding the sail taut. A mild tension aids operation in low winds by creating a steeper angle of attack as the sail partially feathers, but spills most of the higher winds. A strong tension reduces starting ability in low winds by creating a flat attack angle, but spills less energy in high winds.

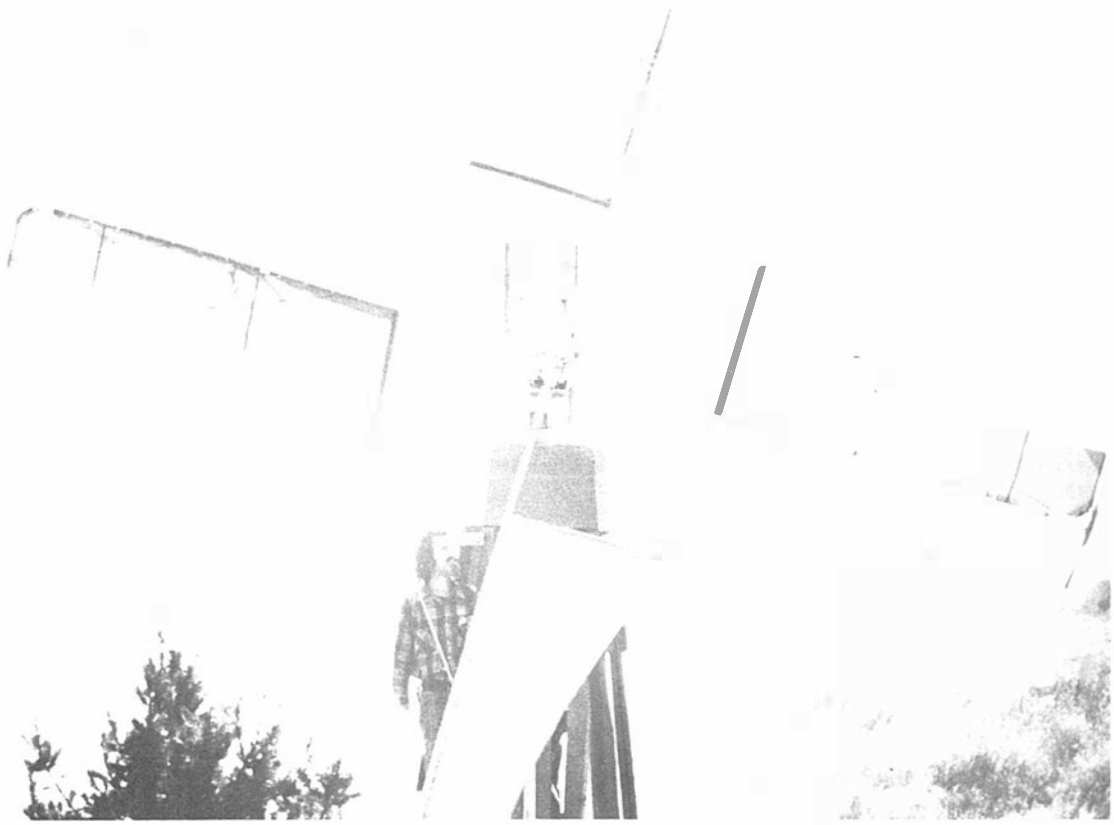
Blade Tip Angles - The angle of the sail to the wind at the tip of each blade also affects the windmill in varying winds. A steep angle creates high starting torque but limits rpm once the windmill is turning rapidly. A flat angle give less starting torque, but once started causes a greater rpm in higher winds.

In our aquaculture circulation application, where continuous pumping is ideal, a mild shock cord tension and a steep tip angle of 40^{o} results in low-wind starting and pumping as often as possible.

We offer these simple cautions in working with the mill:

- Stop the windmill and wear a safety harness while on the tower.
- Avoid allowing the windmill to free-wheel without a pumping load.
- Protect water lines from freezing for winter pumping.

We are, overall, well pleased with the New Alchemy Sailwing. It is beautiful, functional and durable. It performs well the task we ask of it. After four years, it meets the objectives we originally postulated and, in terms of cost, labor, efficiency and usefulness, when contrasted with more standard research and development models, it seems genuinely to qualify as appropriate technology.



The Green Gulch Sailwing

— Tyrone Cashman

The Green Gulch sailwing windpowered irrigation pump was conceived of and implemented jointly by the Arca Foundation, the Zen Center and the New Alchemy Institute. For the Zen Center it represents the first step in the integration of wind energy into their stewardship of their valley.

In the long range, Green Gulch Farm, as a permanent agricultural/natural cycle based community, will reap increasing advantage in food and energy from the recycling of water, of human, plant and animal waste material, and a pragmatic and benign use of wind, sun and gravity-powered water flow.

The community is destined to become a model of gentle stewardship of land — receiving from it a true abundance, while under its guiding hands the soil, ponds, gardens, hillsides and total landscape become richer, more biologically diverse and more beautiful year by year.

The Green Gulch Sailwing provides irrigating water, a constant reminder of natural forces, and basic experience in wind technology for those who helped design and build it and for those who will operate and maintain it. Further wind projects for grey-water aeration, milling, winnowing, water pumping and electrical generation will easily be incorporated by the community through the practical experience and understanding this windmill is providing.

Besides the practical and economic value of this mill, there is an aspect of equal importance and equally appreciated by the community: the mill is beautiful as it turns. The evening sun glows through its sails. It graces the valley as it responds to gentle movements of air. And it is quiet — as it must be (and few windmills are) for its location within yards of the meditation hall in a meditative community.

As a research entity in gentle technologies, New Alchemy sought two goals with this sailwing: (a) to create a wind-powered irrigation system carefully tuned to the bio-region and even to the microclimate of Green Gulch Farm and (b) to advance its research on the problems of inexpensive, durable, simple, high volume/low wind windmills — mills that can also withstand relatively high winds without human intervention.

One of the key problems in inexpensive windmill design is to design for both high and low winds. Since the energy in winds increases *by the cube* of the windspeed, windmills that are light and large enough to produce work in winds under 10 mph are extremely vulnerable to the exponential increases of energy in higher winds.

In designing for the Green Gulch valley, there is the advantage that, for three seasons of the year – spring, summer and fall – when most of the irrigating must be done, the winds are quite tame. Rarely will a wind come up that is over 20 mph. In winter, storms can be expected with winds to gale force and beyond.

The average recorded wind in the lowest wind season – April/May – at the windmill site was 4.44 mph in 1977. The design of a mill which will do regular and significant work in a 4 mph wind regime and still weather winds of 30 to 35 mph without human attention was our goal.

A windmill that is available commercially, such as the American multi-blade sold by Aermotor, Dempster, is the end project of a design that ceased evolving significantly in the 1930's. It begins pumping in light winds due to a 3-to-1 down-stepping gear ratio, giving it added torque to overcome start-up inertia, static head and friction in light winds; but it pays for that torque with a loss of 2/3 potential volume of flow, extra friction in the gear mechanism and considerable expense intrinsic to the production of strong, slow-speed gear wheels.

The rotor, which is made of rigid metal blades, must be turned out of the wind when winds are too high – and extra mechanisms are provided to perform this function either automatically or manually. The construction is of metal.

The advantage of the American multi-blade design is that it is proven to be safe and reliable, requiring little operator attention. These mills are especially well-designed for remote stock-watering operations.

We priced the largest Dempster, which has a rotor diameter of 14 feet and an appropriate tower for our site, and found that the combination turned out to be over $4,000, not including the pump.

The windmills found on the shores of the Mediterranean are designed for the constant, relatively light winds of their region. Cloth is used for sails and wooden spars, windshafts and even wooden bearings are traditional. These mills are inexpensive and responsive to light winds, but their sails must be furled or removed before a storm or if the mill is to be left unattended for a long period of time. Such constant watching and attention are not to be expected of the American farmer or horticulturist.

For several years, New Alchemy has been engaged in the development of simple, low-cost sailwing water-pumping windmills which would be adaptable to diverse wind regimes and which would combine the best qualities of the American multi-blade and Mediterranean mills. The Green Gulch Sailwing may not be that model yet, but it is, on several fronts, a large step forward in the improvement and refinement of the basic design.

Parallel to the development of New Alchemy Sailwings, a small group of missionaries in Omo, Ethiopia, have been developing and testing a variety of sailwing mills for low-level irrigation pumping. The results of their experiments are recorded in a book by Peter Fraenkel of the Intermediate Technology Development Group in London: *Food from Windmills* (London: ITDG, Parnell House, 25 Wilton Rd., SWIV 1JS, 1975). These practical experimenters found some of the New Alchemy ideas and data useful in their work and, in turn, some of their results have been helpful in the design of the Green Gulch Sailwing.

DESIGN AND CONSTRUCTION

A. *The Site*

The mill site was chosen by several criteria:

1. Close enough to the water source that the pump at the base of the mill could be no more than approximately 10 feet above the water surface in all seasons. At this distance a pump which operates frequently enough to keep its leather piston rings moist will not need to be primed. This is essential for a windmill pump which of necessity stops operating for periods of time when the wind dies entirely.
2. Good access to the wind. The site is one hundred yards from the nearest obstruction of its own height, a row of windbreak trees, and is directly behind a gap in the trees in the direction of the prevailing winds.
3. Enough space around the tower base to allow additional devices (air-compressor, winnower, thresher, grinder, etc.) to be connected to the present pump shaft should need dictate and appropriate devices be found or built.
4. The mill is located within sight of the office, the dwelling area and the fields. It is not wise to locate a newly designed windmill out of sight. Young people are tempted to climb it while it is working, if no one is looking. Also, if any aspect of the mill needs attention, it can receive it before the mill damages itself.
5. The site is out of the way of walking and gardening traffic.

B. *Tower*

The tower is designed to use low cost, light weight materials, pine 2 x 4's. Tower strength is achieved by spreading weight and windpressure over eight legs. The tower foundation is eight recycled redwood railroad ties, painted with creosote and buried three to four feet in the clay soil. Strength and convenience in mill maintenance is provided by two circular platforms dividing the tower in thirds. Rigidity is obtained by cross-bracing with 1 x 3's on the lower bays and by simply doubling the 2 x 4 legs in the upper bay, which allows maximum wind passage through the tower at sail level.

The advantages of wood over metal towers are: cost, local accessibility and long-life as, with constant slight bending and vibration, wood will not fatigue, whereas metal can.

C. *Turntable*

DESIGN

Purpose:

1. To allow rotor, transmission and pump shaft to rotate 360° freely in the horizontal plane, in response to changes in wind direction.
2. To bear one ton of off-center load without wear or settling on the side opposite the prevailing winds.
3. To allow a minimum orifice of 2 square inches at the precise center of rotation for pump shaft to pass through.
4. To provide the chassis for all tower-top mechanisms.

CONSTRUCTION

We calculated that a free-floating rear axle from a 3/4 ton truck, when set on end, was capable of meeting all these specifications with a large margin. Such axles are available in scrap metal yards throughout this country and in many others around the world. The cheapest and probably highest quality turntable we could have used was this recycled truck axle. At the low revolutions per day of this application, there should be many years of life left in it.

Before the axle can be used for a turntable, the power shaft is removed from the axle, leaving a 3-square-inch passageway in the center for the pump shaft. The brake parts are removed and a 20-inch diameter disc of steel, ¼ inch thick, is welded as a base for the axle to sit on. Braces underneath the wooden tower platform give added strength against lateral pressure from the wind.

Care must be taken to protect the bearings from rust through exposure to the elements. We protected the bearings with an aluminum cowling which covers the entire transmission. Another protective measure used by the Farallones Institute is to grease the bearings well with boat trailer axle grease (designed to be immersed in water) and cover the opening with the appropriate size jar lid, punctured so that the cut edges lead rain water down the pump shaft and away from the bearings.

D. *Transmission*

Purpose: to transfer power from rotary (wind shaft) to reciprocal (pumpshaft) motion with maximum efficiency and durability and minimum expense and complexity.

This is accomplished with a 14-inch diameter steel disc, ½ inch in thickness, welded to a 2-inch sleeve, machined with a keyway and drilled for a hardened bolt. This disc and sleeve fit over the end of a 2-inch cold-rolled steel bar, 32 inches long, which functions as the wind shaft, bearing all the weight of the rotor and transferring the motion of the rotor to the disc.

The disc is drilled with three 1-inch holes, to any of which a 14-inch long, ¾ inch diameter cold-rolled steel bar, fitted with rod end bearings on either end, can be attached. This connecting rod is further encased in a section of galvanized steel pipe for greater strength.

The connecting rod attaches to the vertical pump shaft at a junction point comprised of a steel box welded of ¼-inch plate with two industrial castors welded to each side. These provide a rolling lateral bracing which forces the side-to-side motion of the disc and connecting rod to be translated into pure vertical motion. The castors run in the pathways of steel channels welded to the I beam base.

The transmission and turntable are designed and built for great strength and durability – yet simply enough for someone with welding ability to construct.

E. *Rotor*

DESIGN

1. The rotor was designed to function downwind from the tower without a tail or rudder. This saves weight and expense, since a tail capable of keeping a 20-foot diameter rotor facing the wind must be very long and large. In addition, sails which are able to stretch back away from the wind during gusts are in danger of rubbing against the tower and catching or snagging when winds are strong. If the rotor is downwind from the tower, the stronger the wind, the further from the tower the sails stretch.

2. To overcome the disadvantage, relative to an American multi-blade, of one-to-one gear ratio in extremely light start-up winds, the rotor was made larger. Very little is added to the expense of a sailwing rotor by extending the masts, for example, from seven to ten feet. However, since the area of a disc is quadrupled when the diameter is doubled, the increase of wind energy available to a 20-foot rotor is double that of a 14-foot rotor. This increment of wind energy is further augmented by the increase in mechanical advantage of a 10-foot lever arm over a 7-foot arm. The expense, complexity and weight of a gearbox is thus eliminated.

3. This sailwing rotor is designed for both low and high winds:

a. *Design for low winds*

Large diameter rotor.
Four sails, each sail with wind-catching area of 21 square feet.
The choice to spread 84 square feet of sail, but not more, was made when the ideal solidity factors for slow speed water pumpers were balanced against the need to limit dangerous levels of drag in high winds. The experience of the research team in Omo, Ethiopia, that the co-efficient of power (overall system efficiency) is more a function of windspeed than of number of sails deployed was also a consideration.

More experimentation needs to be done on best tip speed ratios and solidity factors for sailwing windmills. The season-by-season functioning of this mill and testing of different pumping and air-compressing tasks will help in the further refinement of design.

b. *Design for high winds*

The primary design feature of this low-wind-sensitive, moderate-solidity sailwing to withstand the exponential increases in energy in high winds is the flexible shock cord sheet connecting the outboard corner of the sail root to the successive mast. The shock cord brings the whole sail (from root to tip) into tension and, in combination with the snout cord and fiberglass batten sewn into the sail root, creates the correct airfoil curve of the sail.

The second function of the shock cord is to allow the sail to stretch back out of the wind when a sudden large gust hits it, and to bend back spilling the majority of the energy it is receiving in winds above 20 mph. The wind-spilling ability does not interfere with the regular pumping action of the mill – since, no matter how far downwind the sail is stretched by the wind, it always retains enough energy to pump at an efficient rate.

The second design factor allowing the sailwing to withstand high winds is the fact that cloth sails are flexible and can be reefed (a five-minute operation) during stormy seasons. When reefed, approximately three square feet of sail remains deployed at the mast tips. In this condition, the mill will weather gale force winds and continue pumping the whole time.

A third factor of design for high winds is the ability to set the tips of the sails at an angle that is aerodynamically inefficient, thus creating luffing of the sail tips while the roots are being driven before the wind. The net effect of this precautionary technique is to prevent the rotor from overspeeding in high winds, exceeding tolerable centrifugal forces as well as tolerable stroke rate of the pump.

4. The rotor masts are coned downwind by wire-rope stays. The purpose of coning is to create extra rigidity in the mast. Coning is done downwind so that the effect of the pressure of the wind, which would be to bend the mast further, is counteracted by the tendency of centrifugal force to straighten it.

5. The sails are designed with 17-inch tips widening to 38-inch roots, with a catenary curve cut in the trailing edge. These proportions spread the energy of the wind relatively evenly over the length of the mast while the catenary curve prevents energy loss and noise due to vibration of the roach.

6. The tip booms are a new design worked out to provide extra torque in the light wind season by allowing a steeper than normal tip boom angle at start-up. Once the rotor is moving, the tips are designed to return automatically to the correct angle for efficient operation in motion. The final implementation of this tip design has not been accomplished as of this writing.

CONSTRUCTION

1. The masts are standard 1¼ inch, 10 foot long TV antenna masts. These were chosen for their length, low cost ($3.75 when purchased in June, 1977, as opposed to $37.50 for aluminum spars of adequate strength) and for the ease in obtaining replacements with uniform weight.

2. Masts are stayed, front and rear, by 1/8 inch galvanized wire rope, 7 x 19 strands (for essential flexibility). At the 2/3 point on each mast, a wire rope connects it to the preceding and succeeding masts. Thus, in every direction where stress is encountered, the mast is braced. The stays provide a combination of compressive forces causing a curved downwind cone.

3. The rotor is removable from the windshaft by four bolts. A 2-1/16 inch ID steel pipe fits as a sleeve over the 2-inch windshaft. To this are welded four 9-inch sockets 1-1/8 inch ID into which are inserted the four masts. Mast ends have brazed beads for snug fit.

4. The new tip mechanism is created from an industrial castor with wheel removed, welded to 1-1/8 inch OD water pipe which inserts into the mast end – and welded as a T to a piece of light conduit to form tip boom and tip angle control weight mount. The tip boom rotates 360° on the castor double bearings when the sail is not lashed to it. It can be set manually at a given angle by inserting a pin, or left to work automatically by the action of the weight.
5. Sails are made of 5.4-ounce dyed Dacron(R) polyester cloth with Dacron (R) cord sewn into the trailing edge for strength and rigidity. Sail is lashed to the mast by Dacron (R) cord with flexible tubing inserts where the cord passes over the sharp edge of a grommet.

F. *Pump*

DESIGN

Purpose: to receive energy in the form, intensity and speed a 20-foot sailwing delivers and to translate that energy into the movement of water to a high head.

Low speed demands a positive displacement pump. Centrifugal pumps require on the order of 1,000 rpm for efficient functioning.

Reciprocal action demands either a diaphragm or piston pump.

High head eliminates diaphragm pump. It has too many interior square inches for a head that produces 75 pounds per square inch.

A piston pump is ideally adapted to the vertical motion and length of stroke that a windmill can be made to deliver.

Experimentation in Omo, Ethiopia, concluded that two single-acting, commercial windmill piston pumps, operating on a lever arm such that one was voiding while the other was filling and vice versa, increase the volume of flow a windmill can produce by virtually 100 per cent. They discovered that a mill is not significantly slowed when forced to pump on the down stroke as well as the up. We were not able to discover a commercial pump manufacturer who made a double-acting pump adapted to a windmill, so we decided to build our own. In the ITDG report on the Ethiopian research, a design is offered for a double-acting pump which, at the time of the report, had not been built. The pump for the Green Gulch Sailwing was built from that design. In initial tests the pump has proved very well adapted to the windmill. Further testing and shakedown must still be made.

An added advantage was seen immediately in the double-acting pump: the outflow of water is smooth, with very little pulsing. This minimizes the danger common to reciprocal pumps used for high heads, in that they are subject to return shock waves from their own pulses, causing strain and sometimes damage. This is called the "water hammer effect."

The pump is designed with a 2-inch bore. This size was determined by calculations of the back pressure on the piston head due to a head of water eighty feet high. Although the mill was originally intended to pump fifty-two feet above the pond level and, in winter time, eighty feet to the large reservoirs, experience has made us hope that it can pump a head one hundred-fifty feet. If so, we shall be able to use windmill-pumped water in the irrigation sprinkler system which needs 75 psi, as well as the drip-irrigation system which uses only 15 psi.

Since we have three settings for stroke length on the crank disc, 5 inches, 8 inches and 12 inches, a bore of 2 inches may turn out to be right for such high pressures. A head of one hundred-fifty feet, creating 75 psi of static pressure on the face of the piston which is 3.14 square inches, is resisting the piston's motion with 235 pounds of force, not considering friction and inertia.

From testing so far we have no doubts that the mill will pump to the fifty-two-foot holding tank and the eighty-foot reservoirs as designed. In all likelihood, we shall be able to set stroke length for higher volume in winds of the 10 mph range.

CONSTRUCTION

The pump was built from standard parts and pieces available in plumbing and pump-and-well shops. The barrel is a 16-inch section of 2-inch diameter PVC water pipe. Male adapters are glued to this, top and bottom, and screwed into galvanized iron T's at each end. Two 1-inch galvanized pipes with in-line check valves are connected to the T's at each end.

The sucker rod passes through a packing gland which prevents water, when under pressure in the upward direction, from leaking. The piston is equipped with two cupped leathers – one facing upward and one down.

With this design it is possible to disconnect one entry way into the pump so that it pumps on only one-half of its total stroke – and in place of the half stroke – connect another device, such as an air-compressing bellows for grey-water aeration.

This windmill is the most advanced of the New Alchemy sailwings on several counts:

1. It utilizes a far less expensive turntable of a quality equal to the 10-inch ID turntable bearing used on all recent NAI mills.
2. By the addition of a connecting rod, channels and rollers, the pump shaft runs vertically true throughout its length. This allows the shaft to be guided without significant friction and enables the mill to deliver full power on the compression stroke, a necessary condition for the use of a double-acting pump.

The connecting rod apparatus also makes possible greatly increased length of stroke – which allows high volume from a narrow bore pump.

3. The tower is designed with bowed cross braces under compressive load and a second platform. These eliminate the need for the interior guy wires. Tower work is thus more convenient.

4. Power in low winds is increased by the addition of one mast (four instead of three) and by a considerable increase in sail area for each sail.

5. Sail design is improved:

- By the use of 5.4-ounce Dacron(R) sails instead of 3.8-ounce, which should increase the life of the sail.
- Instead of a root boom, as on earlier NAI mills, or a simple shock cord as on the most recent one, the Green Gulch Sailwing has a fiberglass batten sewn into the root edge of the sail. The shock cord is connected directly to this and to the sail, and an additional cord leading out to the snout of the rotor from this point holds the sail root permanently at 22^{o} (except when high winds increase the angle) and keeps the batten bowed to create a correct airfoil in faint breezes.
- A catenary curve is reintroduced (early NAI sailwings had it) and a firming Dacron(R) cord is sewn into the trailing edge.

6. A tip boom mechanism was designed for the New Alchemy Sailwing three years ago, which was to allow the tips a steep pitch out of the plane of the disc for increased start-up torque, then would, as centrifugal force increased, move the tip into the wind for best operating angle. The mechanism was not reliable as constructed, although the concept may not have been faulty. In addition, it was found that in the brisk and erratic winds of Cape Cod a wind-spilling tip mechanism was of greater use than an efficient tip angle so the mechanism was turned backwards to increase the angle out of the plane of the disc with increased speed. However, this mechanism was, in all events, too complex.

The gyroscopically-controlled tip booms, designed for the Green Gulch Sailwing, could prove to be an advance. They are simpler in concept and design, with only one moving part. Final experimental determination of the correct weight for the tip and construction of the weight-mounting device were not achieved as of this writing. This was simply due to the absence of windmill personnel for the first month after initial testing was to have begun. It was not possible to determine the correct weight for the gyroscopic lever without actual tests on the machine. Experiments with a small-scale model of the tip-boom mechanism were successful.

The tip booms as constructed can also be set manually at various angles, either for greatest efficiency and power or for different amounts of drag to prevent overspeeding.

7. With the introduction of the four-masted rotor, it becomes possible to reinforce each mast laterally by connecting it to the preceding and succeeding masts with 1/8-inch wire rope at a point 2/3 mast length from the root.

8. The double-acting pump is an improvement over all pumps New Alchemy had tried with the sailwing up to the spring of 1977. It allows high-head pumping with low back pressure for start-up and allows a range of volumes per stroke from 0.14 gallons to 0.32 gallons. It is tailored to the kind of power this sailwing produces both in form and intensity. It is specifically designed for high-head pumping.

Due to absence of personnel after the completion of the windmill construction, only minimal testing has been done. It was discovered that, with an 8-inch stroke, pumping nine feet up from the pond and directly out into the squash patch at the base of the tower, the mill began pumping in 6 mph winds and continued pumping in an average of 3 mph. It need not be said that this is an extraordinarily light wind for the performing of any useful work.

Testing of revolutions per minute on two occasions has shown that, with a moderate load (12-inch stroke pumping 35 feet above the pond) the tip speed ratio was 3.6 and did not change as the windspeed changed. Tip speed ratio is the ratio of the speed of the wing tips to the speed of the wind. In this case, the tips were travelling 3.6 times faster than the wind. This is a somewhat higher ratio than normal for a water pumper, but such speed is a disadvantage only when it translates into too little torque for light wind start-ups - or when it sends the mill into overspeed in high winds. With the aerodynamic brake (tips set at inefficient angle) and shock cord spilling of excess wind, the mill should prove to be protected against overspeed in winds up to 40 mph. As for starting torque, we have already seen that it is excellent.

It is to be expected that, when the mill is pumping up 50, 80 or even 150 feet, the tip speed ratio will be reduced to normal levels, between 2 and 3. Tested tip speed ratio with no load (pump disconnected) was 4.7.

Informal observation in winds estimated between 40 and 50 mph reveals that the rotor rpm reaches a peak at around 55 and then *slows down* as the winds rise further. This is due to the loss of airfoil when the shock cords are significantly stretched.

A rough idea of the volumes of water flow to be expected in various winds can be had from tests with a 12-inch stroke pumping 35 feet above the water source:

Windspeed (mph)	Rotor rpm	Gallons per minute
5	24	7.68
6	30	9.60
9	42	13.44
10	48	15.36

Now it is obvious to the Green Gulch community, to its many visitors and to those who drive by on Highway 1, that the winds just above the floor of the Green Gulch valley are capable of performing useful work. The development of other practical wind devices, especially to take advantage of the stronger winds found on the hillsides and hilltops, becomes a natural step. Small mills to do single specific tasks can be designed and built wherever they are needed, providing tangible working examples of a gentle, humane and enduring technology.

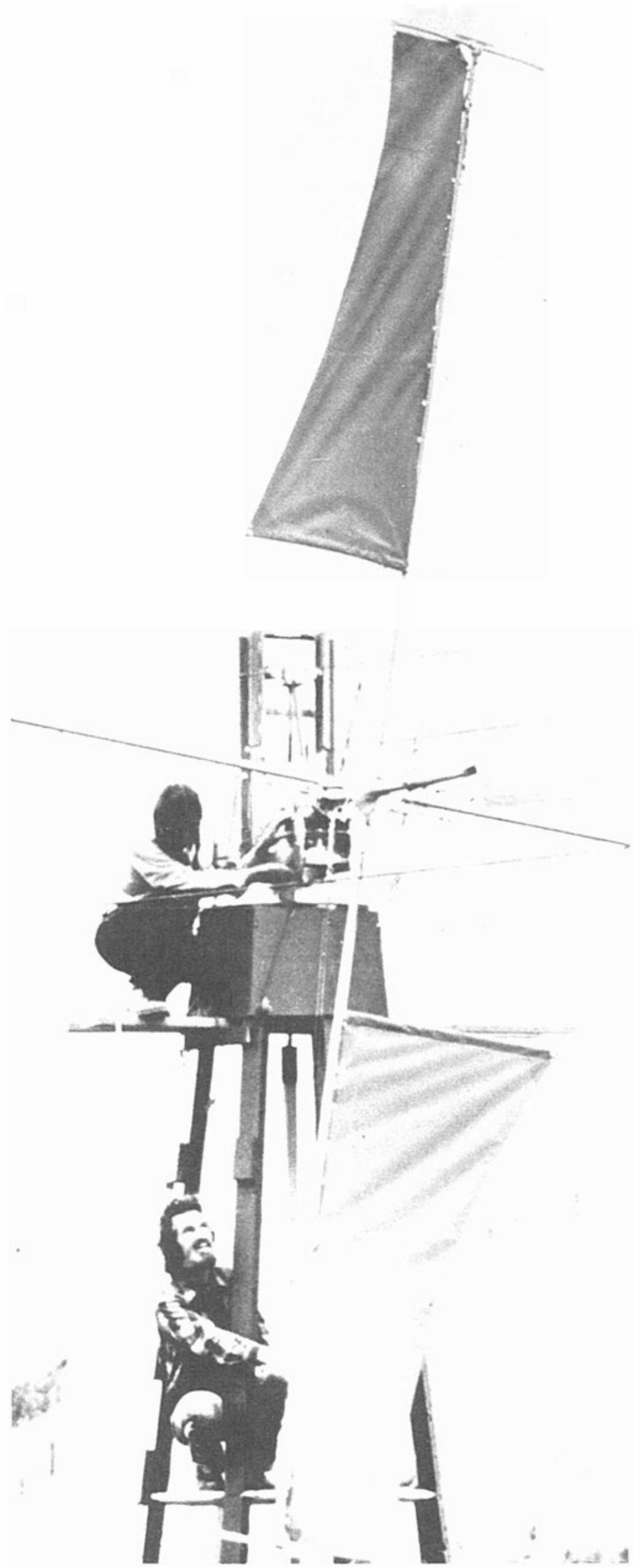
The Green Gulch Sailwing was designed and built by Tyrone Cashman with help from:

Kenneth Sawyer	Eric Larson	J. Baldwin
Barton Stone	Jack Park	Harry Roberts

BUDGET

As of this writing, the expenses for materials were wholly available but not all the hours of labor to the completion of the mill had been tallied.

MATERIALS	COST
Lumber for the tower	$116.64
Windshaft bearings	75.66
Steel for transmission	92.78
Castors for pump shaft	18.28
Tip boom castors	29.82
Rod end bearings	21.26
Steel disc for crank	7.42
Parts for pump	146.28
Bolts and Loctite	3.28
Wire rope, 146 ft.	30.73
Nuts, washers, bolts	8.72
Nuts and bolts	4.86
Misc. hardware	10.51
Turnbuckles and thimbles	5.90
Paint and clamps	13.49
Tail pipe clamps (for booms)	3.18
Antisieze compound	1.00
Stainless steel banding	25.02
Drill bits and files	25.61
Tower paint	15.96
Extra tower paint	15.96
Aluminum sheet for cowling	25.44
Sailcloth	68.42
Extra sailcloth	9.27
Rotor hardware	56.69
18 bobbins thread	4.77
Fiberglass battens	18.83
Dacron(R) Rope	1.90
Shock cords	14.36
OUTSIDE PROFESSIONAL LABOR	
Machining on windshaft/crank	70.00
Threading connecting rod	17.50
Pump alignment and assembly	40.00
TOTAL	$999.54



New Alchemy Hydrowind Development Program

—Joe Seale

The Hydrowind (R) project began in 1975 as a part of the energy resources for the Ark on Prince Edward Island. An immediate Hydrowind goal was to provide the wind energy component of the Ark's natural energy systems. A longer range goal was to develop a windmill with commercial potential that would be within the economic reach of a family but large enough to deliver worthwhile quantities of electrical power. The first prototype mill — Hydrowind I — is fulfilling performance expectations but will require substantial design simplifications to meet criteria for low cost and simple maintenance. This article surveys the results of the Hydrowind program and indicates new directions emerging from current research.

The innovative aspect of the Hydrowind system is the use of a hydraulic pump at the top of the mill to receive power from the rotor and deliver the power in the form of pressurized hydraulic flow to ground-based equipment. Of the many alternative means of using hydraulic power on the ground, electricity generation was chosen for simplicity, versatility and complementarity to most equipment used in modern dwellings.

To generate electricity, a hydraulic motor driven by the flow of fluid from the top of the mill turns a permanent field, brushless electric generator. The alternating current from the generator varies in both voltage and frequency with windspeed changes and is incompatible with the fixed voltage (115 volts) fixed frequency (60 cycles per second) utility lines. To overcome this incompatibility, an electronic synchronous inverter transforms the wind-generated electricity to the proper voltage and frequency and combines it with electricity from the utility. The installation obviously is not therefore designed for stand-alone operation, but instead substitutes wind power for utility power in the amounts available from the mill. When wind generation exceeds the Ark's consumption, surplus power goes out through the utility lines and becomes an input to the power grid. Under these conditions, the windmill is like the many other electric generators linked together by the power grid, each adding its contribution to meet the overall demands of houses and industries tied to the grid.

To limit maximum rotor speeds, the machine uses a hydraulically-driven piston to control the pitch of the rotor blades. The piston, in turn, is controlled by a hydraulic valve operated by centrifugal weights (Figure 1) in a mechanism analogous to the flyball valves that vent steam to govern a steam engine.

HYDROWIND I SPECIFICATIONS

Tower: 40 ft. Dunlite angle iron tower
Rotor type: horizontal axis, 3 blade, variable pitch turbine
Rotor dimensions: 20 ft. swept diameter, 15 in. constant chord blades
Maximum rotor speed: 125 RPM for winds above 22 mph.
Maximum electrical power: 4 KW for winds above 22 mph.
Power transmission stages:

1) 3 to 1 timing belt step-up from rotor shaft to swashplate piston pump
2) pump hydraulic output drives hydraulic motor for additional speed step-up of 2.5 to 1, yielding net effective gear-up to generator of 7.5 to 1
3) hydraulic motor drives permanent field brushless AC generator
4) generator interfaces to AC power lines via Gemini synchronous inverter

Governing stages:

1) centrifugal flyballs open pilot operated hydraulic valve (unit by the Woodward Governor Company)
2) valve opening controls spring return of pitch control cylinder
3) pitch control cylinder controls cam-followers regulating blade pitch

Failsafe: Loss of hydraulic pressure always causes blades to return to full feather. Thus, pump failure or broken hydraulic line feathers mill. Automatic hydraulic pressure dump to feather blades is triggered by hydraulic overpressure (indicative of mechanical or governor failure) or by excess vibration.

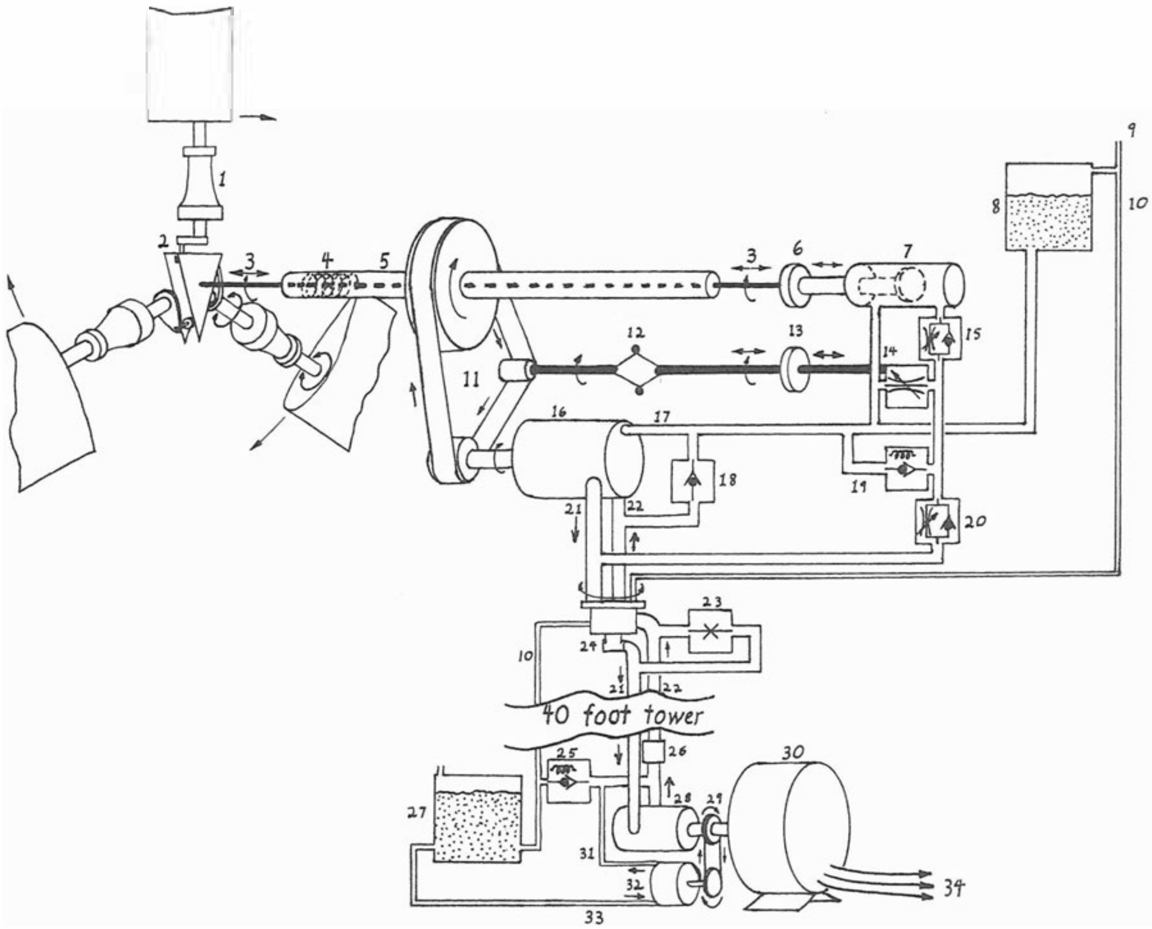


FIGURE 1 - *Key* -

1: Spindle (one of three) with pitch change bearings – this assembly is structurally joined to drive shaft (5).

2: Cam follower (one of three) – causes blades to pitch back when pitch control rod (3) moves to right.

3: Pitch control rod.

4: Pitch return spring (compression; dotted line, inside drive shaft, pushes pitch control rod (3) to right).

5: Rotor drive shaft.

6: Thrust bearing.

7: Pitch control piston and cylinder.

8: Hydraulic oil reservoir.

9: Air inlet - siphon break.

10: Reservoir overflow drain line.

11: Timing belt and pulley assembly – from drive shaft gives 3 to 1 step-up to hydraulic pump (16), 6 to 1 step-up to flyball governor (12).

12:) 13:) 14:) Flyball governor assembly consists of flyballs (12), bearing (13), and hydraulic pilot valve (14) which opens when shaft from flyballs moves left. When valve opens, it allows fluid flow to left through it, permitting hydraulic piston (7) to move to right under force of pitch return spring (4) causing blades to pitch back. (Governor is a single encased manufactured unit.)

15: Needle valve with one way check valve – needle valve limits rate at which pitch control piston moves to left, while the check valve permits rapid motion of piston to right to feather blades.

16: Hydraulic pump – swash plate, 7 pistons.

17: Case drain for pump – pressure inside pump and leakage around pistons cause flow from case drain to keep reservoir (8) filled.

18: One way check valve permits flow from reservoir (8) to keep return line (22) filled when mill is not running.

19: Pressure relief valve limits maximum pressure to governor valve (14).

20: Needle valve with one way check valve – the needle valve acts as a pressure divider in conjunction with governor valve (14) while check valve permits rapid return of pitch control piston to right (feathering blades) when hydraulic pressure drops suddenly, as when bypass valve (23) opens.

21: High pressure line from hydraulic pump to hydraulic motor.

22: Low pressure return line.

23: Electrically operated bypass valve – opens when voltage is removed, dumping high pressure to return line and causing rapid feathering of rotor blades.

24: Hydraulic rotary union – permits top of windmill to turn to track wind without rotating hydraulic lines to ground.

25: Pressure regulating valve – maintains constant low pressure on hydraulic return line (22) during pump (16) operation, keeping the line filled with slight pressure at top to prevent pump equitation while holding check valve (18) closed.

26: Oil filter.

27: Main hydraulic oil reservoir.

28: Hydraulic motor.

29: Belt drive from hydraulic motor (28) shaft to booster pump (32).

30: Electric alternator - 3 phase, fixed field, brushless.

31: Output line from booster pump – carries low volume, low pressure flow to pressurize main return line.

32: Hydraulic booster pump.

33: Return line to booster pump.

34: Three phase AC electric lines to Gemini synchronous inverter, the Ark, and the power grid.

To gain perspective on the relative merits of the existing Hydrowind machine and proposed modifications to it, we need to explore some of the efficiency and control characteristics of horizontal axis windmills. Power available from the wind varies constantly from too little to use to enough to destroy a wind machine. Therefore, efficiency and control design problems split into two categories. When windspeed is insufficient to cause structural damage or power plant overload, emphasis falls on efficient extraction of the largest possible fraction of the power potentially available in the wind moving past the rotor. For higher winds, design emphasis shifts to protecting the rotor, tower and power plant (generator, pump, etc.) from overload. As a secondary emphasis, once safety is assured, the wind plant should recover from high winds the largest possible fraction of the maximum power it can safely handle.

Considering first the high-wind design questions, there are four important methods used singly or in combination to limit: a) rotor speed or power and b) disc drag, the axial wind force that bends rotor blades and the tower.

1. *Blade feathering,* the governing mechanism of Hydrowind I, is the most commonly used method on large windmills. At full power operation, the flats of the rotor blades lie nearly in the plane of the rotor disc (Figure 2a), cutting across the wind and catching its full force. Part of the aerodynamic blade force lies tangential to the rotor disc and generates torque, while the other, generally larger, disc drag component exerts its force downwind parallel to the rotor axis, delivering no power (Figure 2a). Feathering the blades back (Figure 2b) reduces the aerodynamic pitch angle, which reduces blade lift, thus decreasing both rotor drag and torque. If pitch is adjusted to maintain constant rotor speed and torque with an increased wind through the rotor (Figure 2c), an increased fraction of the total blade lift vector becomes torque, so that total blade force becomes smaller, and both blade bending forces and tower forces actually decrease with increasing wind at constant power. Blade feathering has the potential of minimizing blade and tower stresses while maintaining full power, thus ideally fitting both criteria for governing. However, if rotor blades feather in response to rotation speed alone, gusts can cause severe stresses.

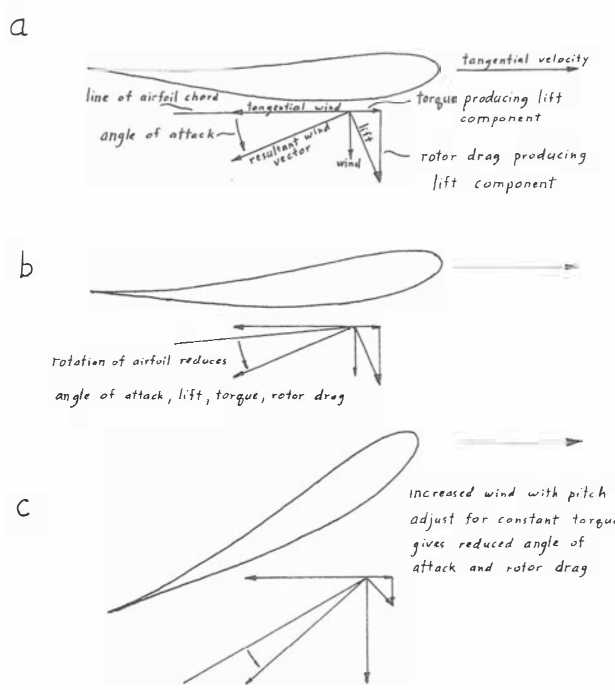


FIG. 2

Suppose that a rotor is operating slightly below governing speed when the wind increases suddenly. Rotor drag immediately increases, but at first the extra torque goes into speeding up the rotor. Thus, rotor speed and shaft power levels at first remain within safe limits as the rotor accelerates soaking up the extra wind power, but the blades and tower experience stresses associated with the greatly increased total wind power.

There are two ways in which a blade pitch control governor can prevent high gust stresses. One method is to use a conversion plant, almost always a synchronous operation electric generator tied directly into an AC power grid, that forces the rotor to turn at rigidly constant rotation speed. With a synchronous generator, the frequency of the power grid enforces a lock-step constant speed rotation on the generator, and the generator, in turn, enforces a proportional constant speed (depending on gear ratio) on the rotor. Blade pitch is then controlled by feedback to maintain constant generator power output, which amounts to regulating pitch for constant rotor torque. Any change in torque causes only a brief transient change in rotor speed after which the power lines reimpose fixed rotation speed at a slightly different phase angle relative to power line phase (Figure 3). Because the rotor is held so rigidly to fixed speed, any wind change is reflected with little delay in a change of generator power. This makes possible rapid feathering response to gusts.

Hydrowind I is not a synchronous operation windmill, so constant speed power governing is inapplicable. The only alternative is to make blade pitch responsive to wind force on the blades or, through some mechanism, responsive to measured wind near the rotor center. The New Alchemy sailwing windmill responds to force on its sails through the elastic mounting of the sails, so that they give way to high wind forces and spill air. But the Hydrowind I blades are not constructed and pivoted to tend to feather passively under stress, so the only alternative would be a complex automatic control system responsive to both rotation speed and either blade stress or windspeed. Such a mechanism would be difficult to make reliable and would not be worth the expense. Confronted with this problem, we opted to derate the governor-limited maximum rotation speed of the mill to a value where a second governing mechanism would protect the blades and tower: aerodynamic blade stall.

2. *Aerodynamic blade stall* is the second of the four major governing methods over
   a) speed or power and
   b) rotor drag

When lift-generating flow which follows airfoil contours breaks down at high angles of attack, stall results (Figure 4). As airfoil angle of attack increases up to the stall region, lift increases in proportion to angle of attack while airfoil drag (not to be confused with rotor drag, which results primarily from airfoil lift forces) is very low. As flow separation sets in, airfoil drag increases sharply while lift decreases. Airfoil drag operates in such a direction as to reduce the tangential or torque-producing force of an airfoil. Thus, stall of all or a part of the length of windmill blades will reduce torque and rotor drag. If rotor speed is held constant, then increasing wind speed will cause increasing blade angle of attack and ultimately blade stall. (Note Figures 2b and 2c, where blade angle of attack would have increased going from 2b to 2c if the blade had not pitched back to maintain constant torque.) When blade stall progresses through a rotor, torque may increase, remain about the same, or decrease, depending on blade shape. If a rigid, fixed pitch rotor has any starting torque, then sufficiently high winds will ultimately result in unsafe torque levels, but care in design can assure that "sufficiently high winds" means winds unlikely to occur during the life of the mill. Rotor drag increases are slowed by blade stall, but, as with torque, sufficient winds will produce rotor drag exceeding levels encountered before stall. Thus, design of stall-governed rotors must conform with the built-in limits of the stall mechanism. That design within these constraints can be successful is borne out by two well-tested stall-governed windmills, the 200 KW Danish mill at Gedser, and the 150 KW mill being tested at Cuttyhunk Island, Massachusetts.

For aerodynamic blade stall to operate, some other mechanism must first limit rotor speed. Otherwise, the rotor blades would continue to speed up with increasing wind, which would prevent increases in blade angle of attack. The usual mechanism for large windmills feeding into a power grid is the phase-lock property of generators connected to an AC grid, as was discussed in relation to power governing by blade pitch control. However, there are many types of wind energy conversion plants that can be designed

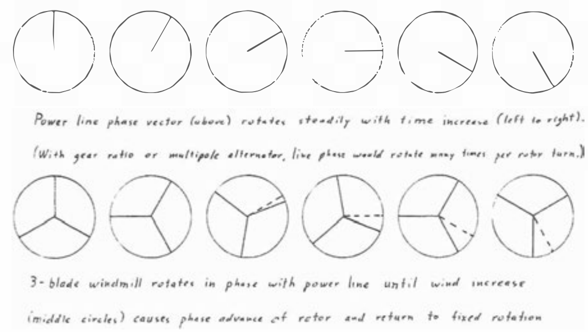


FIG. 3

to present a steeply increasing load on the rotor above some predetermined rotation speed. One such alternative can be accomplished through adjustments in the Gemini synchronous inverter such as Hydrowind I uses. There are numerous possibilities for back-torque speed governing in stand-alone units. Some of these possibilities are the subject of future New Alchemy research plans.

3. *Rotor yaw control* is the third governing mechanism, whereby a rotor disc is turned out of perpendicularity to the wind to reduce the component of wind crossing the rotor disc. (Figure 5 depicts a simple passive yaw control mechanism.) There is a major limitation to the effectiveness of rotor yaw control: the gyroscopic inertia of a spinning rotor limits the speed with which it is possible or safe to reorient the rotor. Winds can change direction faster than a rotor can reorient to avoid the perpendicular force, so there are times when blade forces are limited only by stall. Provided a rotor is strong enough to withstand maximum forces, yaw control can govern rotor speed, though such a system will allow significant speed variation during the time lag between windspeed changes and adjustments in rotor heading.

4. *Aerodynamic spoilers* reduce rotor airfoil efficiencies by disrupting flow and causing turbulence and blade drag. A very small tab automatically extending from a rotor blade upper surface and cutting straight

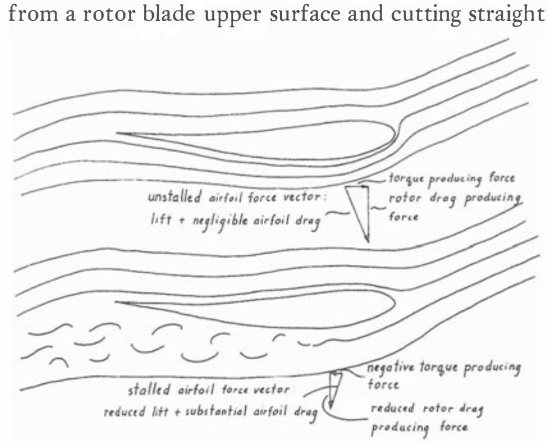


FIG. 4

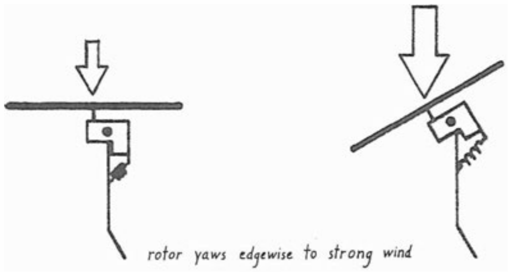


FIG. 5

across the wind flow can suffice to slow a rotor. Automatic spoilers can govern rotor torque or rotor speed but generally not rotor drag, so spoiling relies on blade stall to limit rotor drag.

Having considered high-wind protection and governing, we now come to the area of efficiency maximization in safe winds. Any windmill will be most efficient at one particular rotation speed for any given windspeed. Optimum rotor speed always varies almost exactly in proportion to windspeed. Define tipspeed ratio, τ, by

$$\tau = \frac{\text{rotor tangential speed}}{\text{windspeed}}$$

Then constant optimum proportionality between tipspeed and windspeed implies that optimum efficiency occurs at a fixed tipspeed ratio.
Define coefficient of performance, C_p, by

$$C_p = \frac{\text{recovered power}}{\text{power in the wind}},$$

where "power in the wind" means kinetic energy per unit time contained by the air moving undisturbed past an area equal to rotor disc area. Empirically, C_p is a function only of τ (see Figure 6 for examples) and is virtually independent of windspeed at fixed τ. Betz's limit, .5926, is a widely accepted theoretical upper limit to achievable C_p, and .4 is considered a good practical C_p.

C_p is zero at zero tipspeed ratio because a windmill that is not turning (τ =0) cannot deliver power. However, starting torque of a rotor may be critical for getting a load unstuck and moving in order to make blade power transfer possible. Positive displacement pumps (whether air, water or refrigerant) operating against a pressure head always present special low speed torque requirements for a windmill, with the result that mills designed for pumping tend to look quite different from, say, electricity-generating mills. High starting torque requires large blade area with the blades pitched back typically at least 30°. If the pitch of such blades is fixed, then torque and C_p reach zero at τ =2 or less. With pitch control designed to flatten blade pitch as τ increases, a high starting torque rotor can operate efficiently up to tipspeed ratios of 5 or 6. Thus, a pitch optimizing windmill is potentially versatile at delivering power to loads with differing torque requirements.

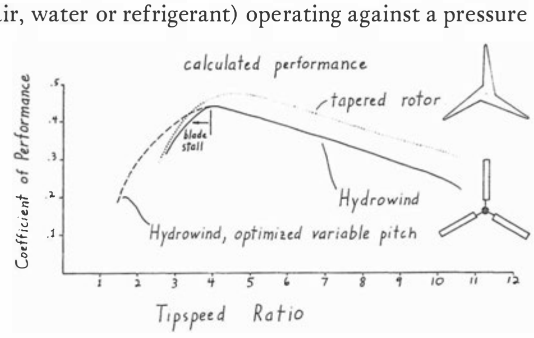


FIG. 6

The blades of Hydrowind I have sufficient area to develop good starting torque when pitched back. The blades always come to full feather when the mill stops or when, for any reason, hydraulic pressure drops to near zero at the pump outlet. Thus, this mill can start high starting torque loads. And, as long as load torque increases with rotation speed, this mill will smoothly flatten its blade pitch with increasing windspeed, rotor speed and load torque, until it achieves the maximum allowed pitch angle. (See Figure 1 for the hydraulic pitch mechanism.) At maximum pitch, Hydrowind I's blades perform efficiently over a broad range of tipspeed ratios (Figure 6). In fact, the proportions of Hydrowind I's blades are ideally suited for performance optimization through pitch control with "difficult" loads such as pumps and compressors. Also, Hydrowind would fit well into most electricity generating loads if blade pitch angle remained fixed at the highest pitch setting.

Despite Hydrowind I's high potential versatility, there are two common load types for which it is difficult or impossible to achieve optimal pitch control. First, there are problems with loads of virtually constant back torque at any shaft speed. Constant back torque implies constant hydraulic pressure, which, in turn, implies constant pitch (Figure 1). No adjustment to the pitch control mechanism can cause pitch to vary in an efficiency-producing way for such a load, which is characteristic of load curves for most pumps and compressors. The second problem arises with loads that produce very little low speed back torque. Such loads include centrifugal water pumps operating to overcome a significant static head and electrical generators operating into some loads, particularly through rectifiers to batteries. With little back torque and back hydraulic pressure, the rotor blades remain at full feather, so the rotor cannot possibly turn fast except in storm winds. Without turning fast, the system cannot develop hydraulic pressure. So, the system is stuck at full feather. It is possible to remedy either of these problems through hydraulic controls at the bottom of the mill. For example, an appropriately controlled servo-valve could provide hydraulic back-pressure at low flow rates only, thus allowing the mill to start with low starting torque loads. In the case of constant torque loads, a variable displacement hydraulic motor could modify the mechanical advantage of the rotor on the load and cause pitch to vary. But once one starts adding hydraulic load-adapting controls, the need for pitch optimization vanishes. With adaptations of standard hydraulic components, it is possible to match virtually any type load to a fixed pitch rotor.

Fully debugged, the hydraulic pitch control mechanism on Hydrowind I has cost far more than the hydraulic power transmission. As we have suggested, relatively simple controls in the transmission itself can move toward eliminating the need for pitch control. On this basis, we intend to abandon pitch-controlling mechanisms on future projects and concentrate on

a) developing an optimum rigid rotor system and
b) developing load adaptations that allow a rigid rotor to operate efficiently and be speed-governed by the load.

Hydraulic power transmission should play a key role in some but probably not all load adaptation problems we can anticipate. While some special tasks might be accomplished best without hydraulics, we suspect that hydraulic power transmission will be the best solution for an adaptable, economical general-purpose windmill.

In the rigid rotor development area we are examining the advantages of tapered rotor blades. The broad blade tips of Hydrowind I contribute starting torque at full feather, but at fixed maximum pitch, which would be the only pitch for a rigid rotor, the large width of the tips detracts from aerodynamic efficiency at all speeds. Not only would narrow tips work more efficiently (Figure 6), they would develop lower peak forces at maximum lift angle simply because of reduced tip area. This implies significantly less bending stress in the blade roots as well as in the tower. The blade construction of Hydrowind I is not adaptable to tapered plan form. The most likely candidate for tapered blade construction is fiberglass lay-up.

In the load adaptation area, we are examining several non-electric tasks adaptable to wind technology: water pumping, air pumping, heat pumping (i. e., refrigerant pumping), refrigeration and heat generation by friction. Air and refrigerant pumping have the greatest need of hydraulic transmission approaches. Water pumping is probably best accomplished by mechanical drive through a vertical shaft to a centrifugal pump designed to govern windmill speed by a steeply rising torque curve. Friction heating uses fluid friction and a similar centrifugal pump speed governor concept. The property that lends great interest to these particular thermal and water pumping windmill tasks is storage. Pumped water can be stored for later use in an elevated or pressurized reservoir. Heat can be stored in low grade form in water and in higher grade form in heat-of-fusion of paraffin wax or sulfur. Cold can be stored in heat-of-fusion of substances like ethylene glycol, so that food freezers can be kept well below freezing during periods of no compressor power. Electricity remains expensive to store, so storage of other forms of energy holds great interest.

We expect our next major windmill construction project to result in a rigid tapered rotor to be controlled by a redundant combination of load control of rotor speed, yaw control of rotor speed, a mechanical brake to control rotor speed, and stall to control stress. The design should be much simpler and more economical than Hydrowind I.

In all the designs we are considering, we anticipate a fusion of high and intermediate technologies. Components like hydraulic pumps and transistors are available from industry and there seems no good reason to forego their use in domestic designs, but, for an economical windmill that can be built and repaired in shops of moderate capital investment, the high technology components must be standard production units that fit, in modular fashion, into a relatively simple structural framework. Further, the workings of the mill should be easy enough to see and understand that a windmill owner/operator with minimal training can keep the mill running. Some of the mechanisms of Hydrowind I have required precision machined components not available off-the-shelf, and this presents a formidable economic barrier to establishing small scale production. The machine has failed to be an encouragement to innovators who have come to examine and learn from it. Instead, it has taken on that inscrutable complexity of technologies like automotive emission control equipment with the unwritten message in the very structure (often reflected in the label): "Hands Off. Refer Service to Qualified Professionals Only." We have learned that there are simpler ways to make a windmill, ways that encourage a broader-based, more diverse and stable participatory technology.

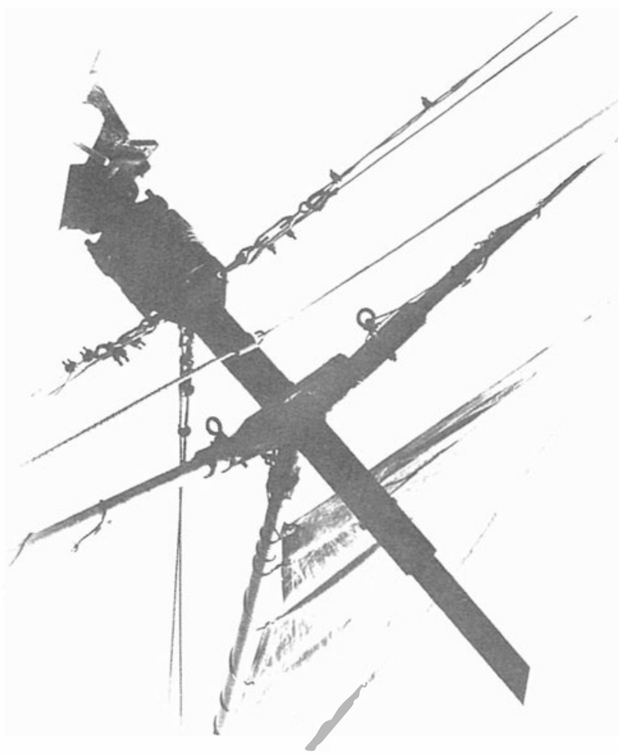


Photo by Hilde Maingay


Land
and Its U

The range of articles for this section this year could only be subsumed under a heading as broad and amorphous as this one. It begins, as is becoming traditional, with Hilde Maingay's and Susan Ervin's annual reports on their work of the preceding summer. The course and the results gleaned from our agricultural experiments are, through these reports, quite explicit. What can only be implied through reading is the beauty and the binding qualities of the gardens. If New Alchemy can be said metaphorically to have a heart it is there, where our food is grown, flowers proliferate, and we spend time together working in silence or talking.

A recent addition, or extension rather, of our efforts in food production has been the raising of earthworms. Although considerable time in other years has been expended in gathering worms to feed the fish, Jeff Parkin's article, "Some Other Friends of the Earth", tells of our first attempt to grow them. It is not only their undisputed usefulness as high-class fish food that attracts us, but their importance in soil fertility, and their energetically-efficient recycling capabilities — as bio-converters, as it were.

Earle Barnhart's article, "On the Feasibility of a Permanent Agricultural Landscape", mirrors what has become, for him, a major focus and reflects a deep interest and direction for the entire group. In his writing, Earle indicates that there is rarely a large margin of profit to be had from careful, far-sighted land management because, in order to preserve the soil and the biological integrity of a landscape, forest or otherwise, much of the produce must, in some form, be recycled or returned to the land. Nature seems to prefer tithing to profit. Perhaps, in this regard, the human psyche has evolved a kind of motivation that is not in sync with natural systems and does not, therefore, have survival value. For while Russia and even China find that, without allowing some self-interest as a driving force, they are hard-pressed for incentives in exhorting production quotas, natural systems go on demanding replacement and sustenance for continuity. It seems a forest does not understand profit. Did Druids?

NJT

Photo by Hilde Maingay

Mexican Bean Battles

— *Susan Ervin*

The Mexican bean beetle *(Epilachna varivestis)* is one of the most persistent insect pests in our garden. We are prepared to accept some insect damage; the disappointment of a low yield from one crop is usually balanced by a good yield from another. But, year after year, severe bean beetle infestations have reduced plants to skeletons. Although it has been found that soybeans can withstand continuous defoliation of up to 50% without lowered yields, small beans often wither without maturing on badly damaged plants in our garden. In a small household garden, one can watch closely for the appearance of the first beetles in the early summer and kill them. *E. varivestis* overwinters in the adult stage. However, overlooked beetles will reproduce quickly and their larvae will have to be subsequently hand-picked. This becomes impossible in a larger growing area.

Maryland is an important commercial producer of soybeans and interesting work is being done there with a biological control agent for the bean beetle. The control is *Pediobius foveolatus,* a tiny gnat-size wasp from India. The wasps deposit their eggs inside the larvae of the Mexican bean beetle. The larvae consequently turn brown, dry and die; the wasps hatch out of the "mummies." The complete cycle from oviposition to emergence of new adult wasps takes between twelve and twenty-six days. In laboratory observations, the mean number of larvae parasitized by an adult female *P. foveolatus* was 20.3. Forty-three per cent of the mummies did not produce live progeny. In field samples, however, seventy-six per cent of the mummies had live emergence.[1] These high reproductive rates allow populations of the parasitizing wasps to build rather quickly. In soybean field studies, more than ninety per cent parasitization was achieved and chemical spraying was largely unnecessary.[2] *P. foveolatus* is host specific. No other insect except *E. varivestis* can be parasitized. The wasps will not overwinter in the temperate zone and so must be bred in laboratories.

We decided to try *P. foveolatus* at New Alchemy on a small-scale, mixed-variety bean crop. Our situation is more like that of a household garden than the large commercial monocrop field.

Our main bean field, which was approximately eighty feet by thirty feet, was seeded to six varieties of shell beans on June 6. Other bean plantings, including snap beans, occupied an approximately equal amount of garden area.

The first adult bean beetles were seen in the field on July 3. Egg masses were seen on July 8. The larvae are very small on hatching and molt three times, for a total of four instars or pre-pupae growth stages. The wasps prefer the later instars for ovipositing so we waited to place mummies containing *P. foveolatus* in the field until we saw "middle-sized" larvae. One-third of our supply was placed in the field on July 18, one-third July 19 and one-third July 20, for a total of 65 or 70 mummies. We do not know what percentage of these mummies produced live *P. foveolatus.* Because the mummies had been shipped from Maryland and held before field placement, live emergence was, no doubt, less than it would have been under optimal conditions.

On July 29, 11 days after the first release, we found two mummies. Collection of larvae to determine percentage of parasitization was begun on August 1. For each collection, a row of beans was inspected and, if larvae or adults were present, one or two people would collect for either 5 or 10 minutes, attempting to collect or count all *E. varivestis* in one spot before moving on. Counts were made of numbers of adults

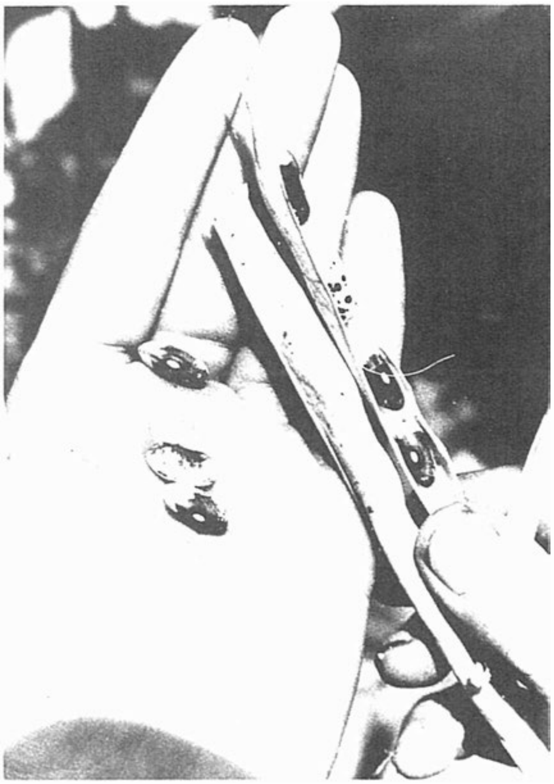


Photo by Hilde Maingay

and numbers of mummies which were not collected as well as numbers of larvae collected. Larvae were held in small cartons in the shade of the bean plants in the field and fed fresh bean leaves daily. Numbers of larvae which mummified or which matured to pupae or adult stages were recorded. Larvae that died but were not clearly parasitized were not included in the data.

In the following table, the "parasitized" figures indicate the number of mummies at collecting time, plus the number of larvae to mummify while being held in the cartons. "Unparasitized" figures indicate the number of adults at collection time plus the number of larvae to pupate or become adults while being held. Collecting periods and number of collectors varied, so comparative population levels cannot be determined from the chart.

Collection Date	*No. Unparasitized*	*No. Parasitized*	*% of Parasitization*
8/1	19	14	42
8/15	12	21	64
8/18	5	48	90
8/22	0	69	100
8/24	3	89	97
8/28	1	73	98
8/29	9	50	85
9/5	11	20	65
9/19	2	47	96
9/13	4	35	90

These figures cannot be taken as actual percentage of parasitization in the whole population because, for one reason, adults are quite mobile and often escape counting, which leaves "unparasitized" figures lower than the actual unparasitized population. Also, it is possible that larvae which died while being held in cartons, and thus were not included in the data, were actually unparasitized. Damage to bean plants was substantial and populations of beetles remained high. For example, five minute collections by one person on August 1, August 27 and September 13 yielded 37, 69 and 46 *E. varivestis,* respectively. Populations did decrease as plants became more mature but the beetles moved to younger plants. They seem to prefer plants that are blooming or forming young beans to very mature plants or to young ones, not yet blooming.

We hope to continue our research. *Pediobius foveolatus* clearly has potential as an excellent control for the Mexican bean beetle. Our experience this past summer seems to indicate that an earlier release is necessary, so that *P. foveolatus* populations can build up in advance of beetle populations. One possibility is an early planting of snap beans as a nursery for the parasites. Alternatively, larger numbers of *P. foveolatus* could be released to surpass the reproductive rate of the beetles.

Photo by Ron Zweig

Photo by Ron Zweig

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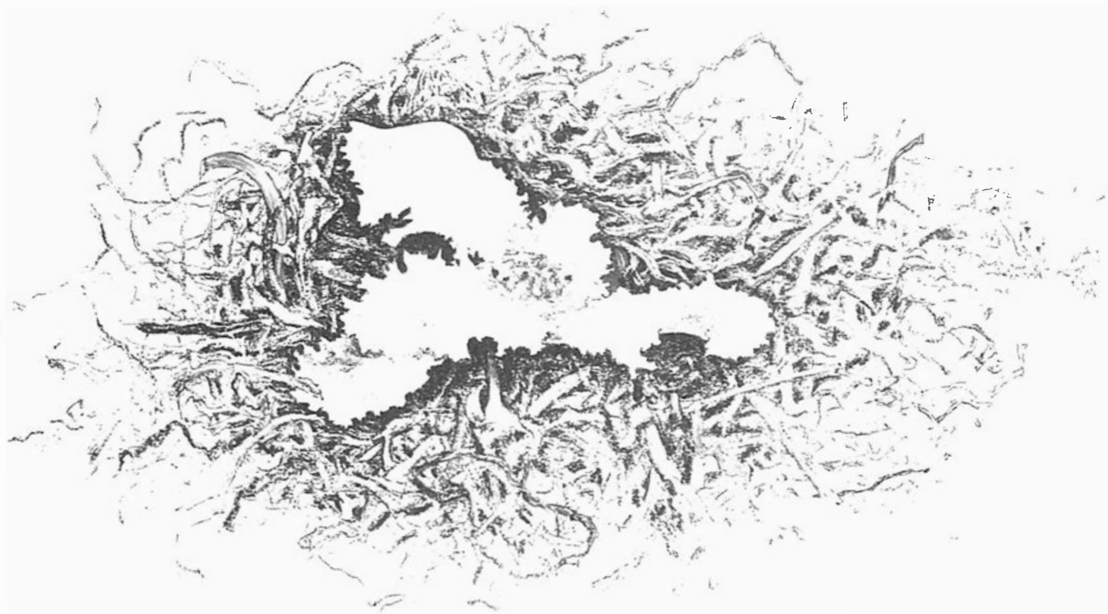
1. Lincoln, C., W. F. Boyer and F. D. Miner. 1975. "The Evolution of Insect Pest Management in Cotton and Soybeans: Past Experience, Present Status, and Future Outlook in Arkansas." *Environmental Entomology 4:* pp. 1-7.
2. Stevens, L. M., A. L. Steinhauer and T. C. Elden. 1975. "Laboratory Rearing of Mexican Bean Beetles and the Parasitc *Pediobius foveolatus.*" *Environmental Entomology 4:* pp. 953-957.

I would like to thank Robert Tichenor of the Maryland State Department of Agriculture for supplying us with *Pediobius foveolatus* and sharing information with us.



Effects of Mulches

— Susan Ervin

Unwatered	Watered	Watered	Unwatered
C No Mulch	F Leaf Mulch	C No Mulch	F Leaf Mulch
B Seaweed Mulch	E No Mulch	B Seaweed Mulch	E No Mulch
A Leaf Mulch	D Seaweed Mulch	A Leaf Mulch	D Seaweed Mulch
Plot I		Plot II	

Table I — PLOT LAYOUT

During the summer of 1976 we conducted an experiment comparing the productivity of mulched and unmulched lettuce. In one trial, we found that the yields of unmulched plots were significantly higher than the yields of plots mulched either with seaweed or with azolla, a small nitrogen-fixing aquatic fern. In the second trial, azolla-mulched plots had higher yields. As mulching is an accepted gardening technique generally believed to be beneficial and as seaweed is a favored mulch, we had expected the seaweed-mulched plots to have the highest yields. Because of the confusing and inconsistent results, we conducted further experiments during the summer of 1977 in an attempt to increase our understanding of mulch/water/crop interactions.

The crops tested were tomatoes, sweet peppers, Swiss chard, lettuce and beets. The applications were a mulch of one-year-old leaf mold and a mulch of "seaweed" (primarily eel grass). To establish a control, some plants received no mulch. Two plots were divided into a total of twelve 12' by 15' sections. Half of the sections received supplemental watering; half did not. The same number of plants of each crop was planted in each section. (Table I.)

Harvesting was spaced to insure that food would not be wasted. Planting and harvesting proceeded as follows:

Tomatoes (Rutgers) — Five plants per section were set out on May 24. Fruits were harvested when they were fully ripe through October 5, when all remaining fruits were harvested, because of the danger of killing frost.

Peppers (California Wonder) — Five plants per section were set out May 26. The harvesting was the same as that of tomatoes.

Lettuce (Ruby) — Trial I. Twenty plants per section were set out on May 16. Five plants per section were harvested July 2, five July 3 and the remaining ten, July 5.

Trial II. Twenty-five plants per section were set out on July 12. Five plants per section were harvested August 22, ten August 30, five August 31, and the remainder September 5. In both trials, plants which appeared largest were harvested first, leaving smaller plants to grow.

Beets (Early Wonder) — Seeded directly in soil on May 18. They were reseeded on June 8 because of poor germination and later thinned, leaving twenty plants per section. Five plants per section were harvested August 2, five August 16, and the remainder August 30. Plants appearing to be largest were taken first, leaving smaller ones to grow.

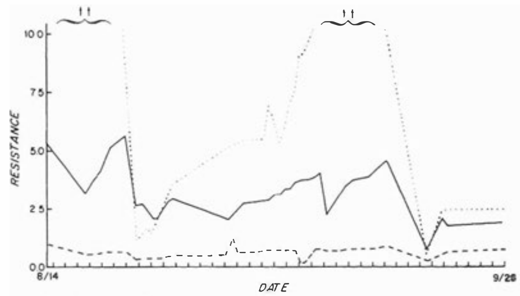
Swiss Chard (Rhubarb Chard) — Twelve plants per section were set out on May 25. About once every week and a half, beginning July 22, as many outer leaves were harvested from each plant as was judged could be taken without damaging the plant.

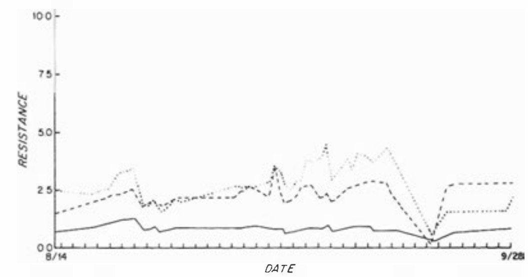
The sections receiving supplemental watering received equal amounts of tap water as often as needed. The crops in the unwatered sections were watered only at planting or seeding and once again soon afterward, to minimize transplanting shock or to promote germination.

The lettuce plants were mulched on May 16 when they were planted. The rest of each section was mulched on June 7. A narrow, bare space was left around small plants so they would not be damaged by the mulch. The mulch was piled more closely around the plants as they grew larger. The depth of both seaweed and leaf mulches was approximately 4 inches. All mulch was renewed on July 11 and 12. The soil surface of the unmulched section was loosened frequently by hoeing. All sections were kept free of weeds.

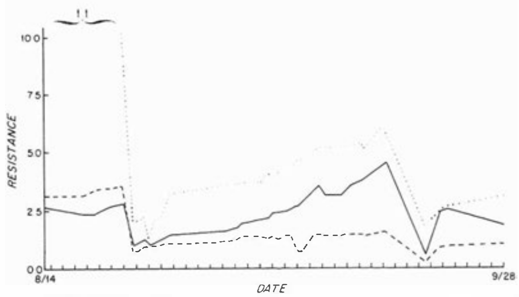
A soil moisture/temperature meter (Soiltest MC-300) was used to gather data on soil conditions. Sensors were installed at depths of six inches and twelve inches in each section of Plot I. A separate thermometer was used to read temperatures at two inches. Readings at

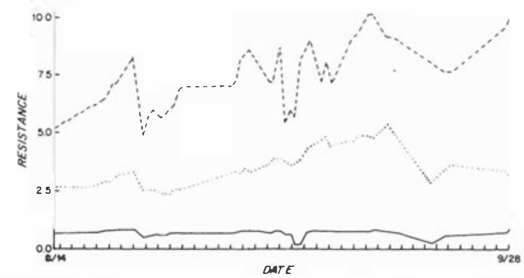
Photo by Ron Zweig



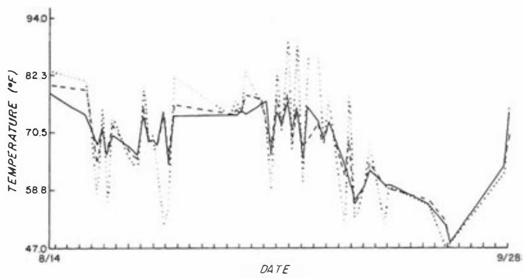


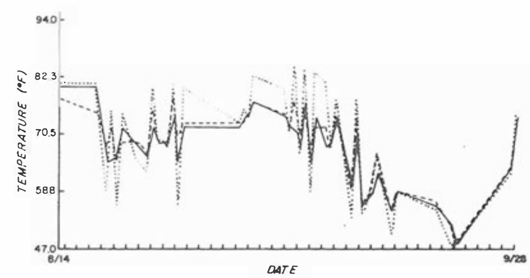
Sections A, B, C — *Moisture Readings at 6" Depth* — Sections D, E, F



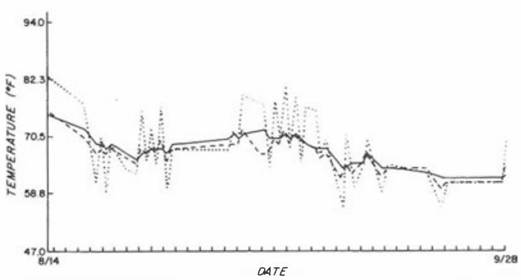


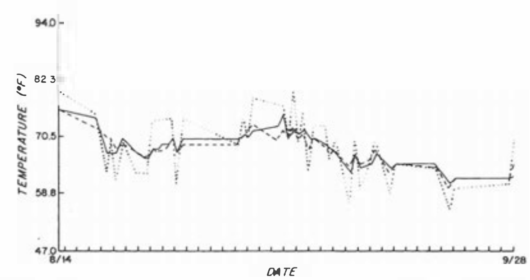
Sections A, B, C — *Moisture Readings at 12" Depth* — Sections D, E, F



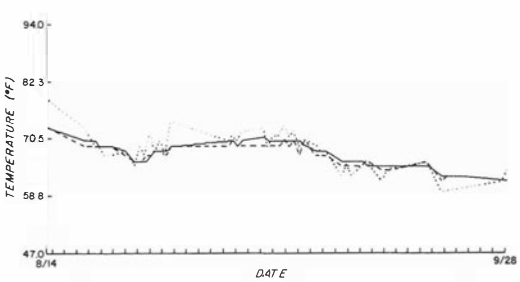


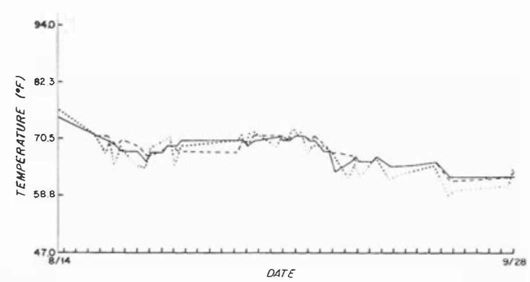
Sections A, B, C — *Temperatures at 2" Depth* — Sections D, E, F





Sections A, B, C — *Temperatures at 6" Depth* — Sections D, E, F





Sections A, B, C — *Temperatures at 12" Depth* — Sections D, E, F

SEAWEED MULCHED (A and D): ————
LEAF MULCHED (B and F): - - - - - -
UNMULCHED (C and E): ··········

TABLE II

the three depths were taken once a day from July 26 to August 18 and twice a day, in the early morning and late afternoon, from August 19 to September 18. Earlier attempts to record data were made impossible by sensors unsuitable for sandy soils. Results are shown in Table II. Low readings indicate low resistance, thus high moisture availability; high readings indicate high resistance and low moisture availability.

The summer of 1977 was not a dry one. There was no sign of wilting in any section at any time. As indicated by the graphs, the unwatered, unmulched section (C) was driest at both depths. Seaweed-mulched sections (B and D), watered and unwatered, were wetter at both depths than any other sections. The leaf-mulched, watered section (F) was drier than any other except for the unmulched, unwatered one (C).

The only apparent difference between section F and the others was a slight slope which, in conjunction with the sand substrate of our soil, could cause rapid moisture loss.

Because we were primarily interested in the comparative effects of the various mulching treatments on soil moisture, we did not establish a calibration curve for relating meter readings to available soil moisture.

Table III

Maximum daily variations at: (°F)	*Leaves*	*Seaweed*	*No Mulch*
2"	13°	11°	27°
6"	3°	4°	15°
12"	1-2°	1-2°	7°

Photo by Ron Zweig

Temperature readings were similar in sections receiving the same mulch. Unmulched sections C and E showed both the highest and the lowest temperatures and the greatest daily variation at all three depths. Daily variation was greatest at 2 inches, least at 12 inches. (Table III)

Table IV shows yields for each crop in each section and for like-mulching treatments combined. Because the number of plants was not identical at harvest, numbers of plants per section of lettuce, chard and beets were equalized by random selection. The loss of one tomato plant and one pepper plant made it possible to consider data from only four plants per section and, because of this small number, the data of the tomato and pepper plant with the lowest yield were dropped from each other section instead of equalizing the numbers by random selection.

An analysis of variance was done using individual plant yields. (Table V) The categories considered were: water effect, mulch effect, water/mulch effect, plot effect, plot/water effect, plot/mulch effect, and plot/water/mulch effect.

No significant effect of mulching or watering was determined except for chard. On the other hand,

Table IV - Yields of individual sections and of like mulching treatments combined - Weights are given in grams

	unwatered leaves		unwatered seaweed		unwatered no mulch		watered leaves		watered seaweed		watered no mulch	
	1A	2F	1B	2D	1C	2E	1F	2A	1D	2B	1E	2C
Lettuce I	1575	2297	2443	1837	1523	1369	2041	1173	1817	2641	1115	2201
Lettuce II	1046	1069	613	897	1186	664	740	896	420	852	932	1008
Chard	4476	6393	11405	9713	4667	6448	4927	4973	9416	8870	6385	5908
Beets	3712	3348	5235	3111	2214	1740	1588	1810	4333	2976	2651	3220
Tomatoes	29448	43497	35330	26154	35085	34458	28960	31277	34427	50202	25800	33531
Peppers	3372	938	2672	2745	3433	3029	1247	2751	2468	2473	2014	2361

	Lettuce I	Lettuce II	Chard	Beets	Tomatoes	Peppers
Leaves	7086	3751	20769	10458	133182	8308
Seaweed	8738	2782	39404	15655	146113	10358
No Mulch	6208	3790	23408	9825	128874	10837

Table V RESULTS OF STATISTICAL ANALYSIS

TOMATOES

Source	*d.f.*	*S. S.*	*M. S.*	*F*	*SIG*
Total	47	290.			
Watering	1	0.	0.	<1	N. S. @ 50%
Mulches	2	10.	5.	<1	N. S. @ 50%
MxW	2	50.	25.	5.1	N. S. @ 90%
Plots	1	18.8	18.8	4.4	97.5%
PxW	1	9.	9.	2.1	N. S. @ 90%
PxM	2	3.8	1.9	<1	N. S. @ 50%
PxWxM	2	42.8	21.4	4.9	97.5%
Plants (PWM)	36	155.	4.3		

BEETS

Source	*d.f.*	*S. S.*	*M. S.*	*F*	*SIG*
Total	167	1892767			
Watering	1	46068	46068	1.3	N. S. @ 50%
Mulches	2	365466	182733	2.6	N. S. @ 50.75%
MxW	2	278277	139114	23.1	99.9%
Plots	1	74088	74088	12.30	99.9%
PxW	1	34172	34172	5.67	98-99%
PxM	2	142815	71408	11.85	99.9%
PxMxW Plants (PWM)	158	951931			

CHARD

Source	*d.f.*	*S.S*	*M.S*	*F*	*SIG*
Total	119	35434186			
Watering	1	57334	57334	<1	
Mulches	2	5084163	2542082	9.73	99.99%
MxW	2	201337	100669	<1	
Plots	1	8823.7	8823	<1	
PxW	1	74152	74152	<1	
PxM	2	255237	127619	<1	
PxWxM	2	173662	86831	<1	
Plants(PWM)	108	29579478	273884		

LETTUCE I

Source	*d.f*	*S.S.*	*M.S.*	*F*	*SIG*
Total	239	382338			
Watering	1	13	13	<1	N.S.
Mulches	2	41254	20627	5.9	N.S. @ 75%
WxM	2	8042	4021	<1	N.S. @ 50%
Plots	1	4200	4200	3.90	95%
PxW	1	4860	4860	4.52	95%
PxM	2	6976	3488	3.24	90%
PxMxW	2	71610	35805	33.3	99.99%
Plants(PWM)	228	245385	1076		

LETTUCE II

Source	*d.f*	*S.S*	*M.S.*	*F*	*SIG*
Total	239	84693			
Watering	1	1638	1638	<1	N. S. @ 50%
Mulches	2	8152	4076	<1	N. S. @ 50%
WxM	2	2039	1020	1.2	N. S. @ 50%
Plots	1	840	840	3.3	95%
PxW	1	3219	3219	12.5	99.99%
PxM	2	8455	4227	16.4	99.99%
PxWxM	2	1747	873	3.4	95%
Plants(PWM)	228	58603	257		

PEPPERS

Source	*d.f*	*S. S.*	*M.S.*	*F*	*SIG*
Total	47	4048642			
Watering	1	172200	172200	<1	N. S.
Mulches	2	225578	112789	5.8	75-90%
WxM	2	120267	60133	<1	N. S.
Plots	1	17214	17214	<1	N. S.
PxW	1	446446	446446	7.1	99.5%
PxM	2	38579	19289	<1	N. S.
PxWxM	2	782759	391379	6.27	99.5%
Plants(PWM)	36	2245598	62378		

Legend: d. f. = degrees of freedom; S. S. = sums of squares; M. S. = mean squares; SIG = significance; N.S. = not significant

there are significant differences in plot, plot/water, plot/mulch, or plot/water/mulch interactions. Mulch and water effects may have been present but are masked by variations among the sections and plots themselves. Chard did show a highly significant effect from the seaweed mulch despite plot variation.

A consistently low yield from one plot or section might have indicated unfavorable environmental conditions which were not readily apparent. However, the effects of plot and plot/water/mulch interactions were not consistent from crop to crop. For example, Plot 2 yields were higher for lettuce, tomatoes and chard, while Plot 1 yields were higher for beets and peppers.

Moisture and temperature data were consistent for sections receiving the same mulch treatment so extreme plot and section variation cannot be attributed to these factors.

Although the causes of plot to plot variation were not determinable, we decided to consider the two plots separately since the differences were significant. Inspection of the data showed a clear trend toward superior yields from seaweed-mulched sections for beets, chard and tomatoes in both plots, as is shown by the figures in Table VI. Mulching of lettuce and peppers did not have a clear and consistent effect.

Chard, beets, peppers and lettuce all had higher yields without supplemental watering whereas the watered tomatoes had a slightly higher yield. However, statistical analysis indicated that none of the differences were significant.

Observations were made on the number of tomatoes affected by blossom end rot. All of Plot 2 showed a much higher incidence of rot, whereas no one mulching treatment was clearly associated with incidence of blossom end rot. (Table VII)

Photo by Ron Zweig

TABLE VI - Yields of Crops for Plot 1 and Plot 2

		Plot 1	*Plot 2*
	Leaves = L	5300	5158
Beets	Seaweed = S	9568	6087
	No mulch = N	4865	4960
		∴ S > L > N	∴ S > L > N
	Leaves = L	9403	11366
Chard	Seaweed = S	20821	18583
	No mulch = N	11052	12356
		∴ S > L > N	∴ S > L > N
	Leaves = L	58408	74774
Tomatoes	Seaweed = S	69757	76356
	No mulch = N	58885	67989
		∴ S > L = N	∴ S > L > N

Table VII
Numbers of Fruit Affected by Blossom End Rot

	Plot 1	*Plot 2*	*Total*
Leaves	42	58	100
Seaweed	29	66	95
No Mulch	9	68	77
Total	80	192	

While the beneficial effects of mulching in reducing weeding and retaining irrigation water are not disputed, we have not yet shown statistically significant increases in crop yields from mulching. However, there was a clear trend toward superior yields from seaweed-mulched crops. Supplemental watering did not significantly increase crop yields during this particular growing season.

We shall continue our experimentation. Sections will extend the full length of each plot to make slope and soil variations as similar as possible.

REFERENCES

1. Ervin, Susan. 1977. "The Effects of Mulching with Seaweed and Azolla on Lettuce Productivity." *The Journal of the New Alchemists (4)*: 58-59.

I should like to thank David Juers for his generous and much-needed assistance with the statistical evaluation. Also, long hours of work by Kim Conroy, Bill McNaughton, Nancy Jack Todd and Rebecca Todd should be acknowledged.

Photo by Hilde Maingay

Photo by Hilde Maingay

A Study of the Energy Efficiency of Intensive Vegetable Production

— Hilde Maingay

In spite of the fact that science has increased our understanding of the complex interdependence between the elements in an ecosystem, the implications of this knowledge are, as yet, not fully understood. Modelling itself on industry, modern agriculture has replaced complexity with relative simplicity. The growing of food is no longer seen as the source of life but rather as a means of making a living. Agriculture has become the business of cultivating land for the raising of profits rather than crops. Decisions determining what and how much is grown, where, whether or not it is grown, when and by whom, do not reflect human needs, but the best-hedged possibilities for profit. To insure profits as many living variables as possible, such as fungi, bacteria, insects and weeds, are eliminated.

A recent cover of the magazine, *MONEY*, reflects this attitude. The photograph depicts a radiant, smiling, tanned, very clean young couple on a tractor. In the background, as far as the eye could see, is one crop — wheat. Superimposed is the subtitle "BACK TO THE SIMPLE LIFE" and another phrase: "*MONEY* was made for times like this" — stereotyped couple, one crop, one machine, a highly "simple" life.

How much longer can we maintain such a simple life support system? Signs of destruction and disruption are everywhere. Soils are eroding, water and air are contaminated. Weeds and insects are returning in greater numbers in spite of intensive spraying. The present economic and political structure perpetuates the semblance of simplicity, holding to the dream that technology can solve these problems and continue to sustain exponential growth. Yet the lag-time between evolving values and legislative response is creating a grassroots movement based on the hope that many small but fundamental changes will result cumulatively in significant change, giving people power over their own lives. With a growing belief in conservation and a steady state economy, many people are seeking the knowledge necessary for a restorative and life-sustaining way of life.

Since the time of our first gardens, we have been addressing ourselves to the question of whether it is possible to achieve average or above-average yields without the use of chemicals and, if so, how much energy and labor would be required. In the spring of 1976, we began an experiment in small-scale food production without pesticides. The test garden plot was one-tenth of an acre, divided into twenty raised beds, as described in *Journal Four*. During the growing season, we collected data on human labor, irrigation water and productivity. Over-all the garden produced the equivalent of three daily servings of vegetables for more than ten people for 365 days.

Because weather could have been an unusually favorable or unfavorable variable the first year, it was decided to repeat the experiment the following year. Higher yields were expected as soil fertility had increased. In the planning stages, I began to ask myself, "Is it possible for land under cultivation to produce average or above average yields without the use of chemicals? And, if so, how much energy and labor would this take?" To gain some background, I called the local extension service to ask about average yields of vegetables and grains, preferably on Cape Cod but otherwise as close to home as possible.

"I am sorry," the agent said, "but I cannot give you any such data. The Cape cannot produce anything but cranberries and some strawberries."

"Well," I said, "maybe you have records on crops grown here twenty years or so ago?" His reply was negative again, as he had not seen anything else growing successfully in the twenty years he had been on the job here. "What about a l-o-n-g time ago, the turn of the century or before?" I asked. And, noticeably impatient, he answered, "Lady, you don't want to know about those figures, because what they called high yields back then, we'll call a poor yield now."

If I hadn't already grown an abundance of vegetables on our land, I should have stopped any gardening or intentions of farming and gone into the construction business.

In the spring of 1977, we planted the same plot as the previous year, again dividing it into twenty raised beds. As before, data on human labor, water and productivity were collected. Cloches were used to extend the growing season. The cloche design, as described in the fourth *Journal*, proved very successful. Over 3,000 seedlings from our small solar greenhouse, the Six-Pack, were transplanted into the garden.

We dug a separation ditch to cut the roots of the trees on the edge of the woods that intrude into our gardens. We planted Jerusalem artichokes at the end of each bed as a buffer between the food plants and the woods. The previous summer, wild rabbits had raided the pea and bean plants, preventing the plants from reaching maturity. This year we shot the wild rabbits and a splendid spring garden resulted.

Although many people were involved in harvesting, weighing and recording the vegetables, three people guided all other aspects of the garden work. Two were summer volunteers and novices in the field, though they quickly demonstrated both their stamina and their sensitivity to the plants. The results of the '77 gardens were as we had hoped: more food was grown with less work and with less irrigation. (See Tables 1A, 1B, 1C, 1D) It is safe to assume that these gardens have not yet reached their upper limits of productivity. Soil fertility increases noticeably each year. And, as our planting scheme improves, we anticipate a steady decline in the human labor needed as well.

Method of establishing the number of portions produced

In 1976, the total amount of edible grams of each variety of vegetable was divided in half. One-half was used fresh; dividing this half by given grams per portion, the total number of portions for that vegetable was found. The other half was considered a cooked vegetable and reckoned the same way. By dividing the given grams per (cooked) portion, the total number of portions was found.

In 1977, we used the same method, changing the proportion between the raw and cooked. One-third of the total amount of edible grams produced was calculated as raw, the remaining two-thirds as cooked portions. It

is our feeling that this is a more realistic reflection of our food habits. While many vegetables can be eaten fresh in season, most have to be canned, frozen, dried or put in a pit or root cellar, for later usage.

PRODUCTIVITY TABLES: Comparison between 1976 and 1977

Portion figures are based on *The Handbook of Food Preparation*, published by The American Home Economics Associations, 1964.

Table 1A 1977 Productivity in Grams and Servings in Relation to 1976 Yield of Raw Salad Vegetables.

Raw Salad Vegetables	Total Edible Grams	Grams Per Portion	Total Portions per Crop 1977	Total Portions per Crop 1976
Cucumber	281,874	133	2119.3	307.7
Lettuce	103,322	77	1341.8	361.2
Beet Greens	8424	30	280.8	--
Collards	7147	30	238.2	--
Kale	9212	30	307	180.9
Spinach	4348	27	161	327.4
Swiss Chard	21,429	38.5	556.5	208.1
Cabbage	19,509	36.5	534.4	2340.3
Celery	16,370	60.5	270.5	141.8
Pepper	2944	38.5	76.4	14
Cauliflower	1672	30	55.7	108.8
Corn*				
Leek	500	35	14.2	184.9
Summer Squash	3396	50	67.9	133.2
Tomato	17,358	100	173.5	228.7
Celeriac	5272	36.5	144.4	--
Kohlrabi	5785	36.5	158.5	210.2
Ground Cherries				
Carrot	19,907	65	306.2	--
Onion	17,297	30	576.5	--
Garnish:				
Herb	--	--	--	--
Onion Top	9083	38.5	235.9	--
Parsley	--	--	--	--
Total No. Portions			7618.7	4747.2
Number of People - 1 Portion/Each Day of Year			20.8	13
			Increase - 60%	

Table 1B 1977 Productivity in Grams and Servings in Relation to 1976 Yield of Cooked Root Vegetables.

Cooked Root Vegetables	Total Edible Grams	Grams per Portion	Total Number of Portions per Crop 1977	Total Number of Portions per Crop 1976
Jerusalem Artichokes	99,836	81.5	1224.9	--
Parsnip	7329	105.5	69.4	85.6
Potato	78,126	81.5	958.5	2052.9
Rutabaga	19,749	81.5	242.3	174.7
Turnip	15,427	98	157.4	133.9
Celeriac	10,544	98	107.5	--
Kohlrabi	11,570	98	118	156.6
Beet	22,002	90	244.4	204.2
Carrot	39,814	80	497.6	186.4
Onion	34,594	98.5	351.2	264.8
Total No. of Portions			3971.2	3259.1
Number of People - 1 Portion/Each Day of Year			10.8	8.9
			Increase - 21.3%	

Table 1C 1977 Productivity in Grams and Servings in Relation to 1976 Yield of Cooked Green Vegetables.

Cooked Green Vegetables	Total Edible Grams - 1977	Grams per Portion	Total Number of Portions per Crops 1977	Total Number of Portions per Crops 1976	Total Edible Grams - 1977
Snap Beans	45,464	62.5	727.4	231.8	14,492
Broccoli	12,020	84	143	318.1	26,722
Br. Sprouts	7428	77.5	95.8	118.5	9189
Okra	7245	88.5	81.8	8.5	759
Peas	19,712	81.5	241.8	13	1065
Sw. Pod Peas	4006	81.5	49.1	--	--
Eggplant	9630	106.5	90.4	241.5	25,725
Winter Squash	28,197	122	231.1	23.8	2913
Beet Greens	16,848	95	177.3	--	--
Collards	14,292	95	150.4	--	--
Kale	18,424	95	193.9	114.2	10,857
Spinach	8696	100	86.9	176.8	17,680
Swiss Chard	42,858	95	451.1	168.7	16,028
Cabbage	39,018	73	534.4	2351.8	171,682
Celery	32,740	77	425.1	222.9	17,165
Pepper	5888	83.5	70.5	11.7	982
Cauliflower	3344	62.5	53.5	104.5	6532
Corn				75	(150 ears)
Leek	1000	68.5	11.2	48.7	4315
Summer Squash	6793	119	57	95.2	11,329
Tomato	34,716	119	291.7	384.3	45,742
Ground Cherries					
Dry Beans	1414	50	28.2	--	--
Wheat					
Total No. Portions			4191.6	4709.0	
Number of People - 1 Portion/Each Day of Year			11.4	12.9	
			10.9% decrease in production over 1976		

Table 1D Total Number of Portions in Each Category - 1976 and 1977.

Portions	1976	1977	
Raw Salad	4,747.2	7,618.7	60.4% increase
Cooked Roots	3,259.1	3,971.2	21.8% increase
Cooked Greens	4,709	4,191.6	10.9% decrease
Total	12,715.3	15,781.5	24.1% increase

Notes on Tables 1A, 1B, 1C, 1D:

Corn: Almost one-and-one-half beds were seeded in corn but had to be reseeded two or three times, as the birds plucked all the soft sprouted seedlings as soon as they appeared above the ground. Interestingly enough, the only successful row was one that had been seeded adjacent to a row comprised of a mixture of broccoli, cauliflower and leek and, in that row, germination was almost 100 per cent. Once the corn seedlings had grown beyond a size that attracts birds, many were transplanted to fill in empty spots. We had, in the meantime, started corn in flats, out of the reach of the birds. These seedlings filled the rest of the space designated for corn. Then, as if this rough start had not been enough, earwigs appeared in mid-season, causing damage to the tassels. Pollination was poor, although four rows may be insufficient for pollination. Beds of corn should probably be adjacent to each other. Finally, when the ears were almost ready for harvesting, the birds returned and stripped most of the ears, leaving little either for us or the cornborers.

New Zealand Spinach and Leeks were planted at the same time as the corn and close to it and were quickly

Table 2 Human Labor Requirements for Different Garden Tasks and Total Labor Requirements of 1976 and 1977

Human Labor	Soil Preparation in Beds Min.	Watering Min.	Weeds and Bugs Min.	Plant and Seed Min.	Total Amount of Labor 1977 Min.	1977 Hrs.	1976 Hrs.
April	300	81	--	273	654	11	18 1/2
May	361	407	265	783	1816	30 1/4	34
June	1053	189	515	1282	3039	50 1/2	78 1/2
July	1260	1747	1250	660	4917	82	86 1/4
August	370	707	510	295	1882	31 1/2	13
September	135	20	--	--	155	2 1/2	5
Total	3479	3151	2540	3293	12,463	207 3/4	235 1/4

Note: 69 minutes/day over a 6-month's period.

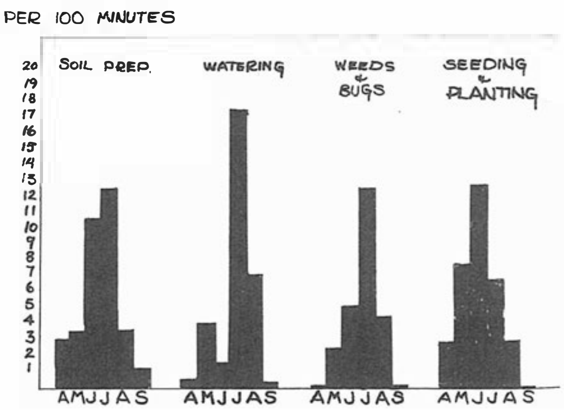


Fig. 1

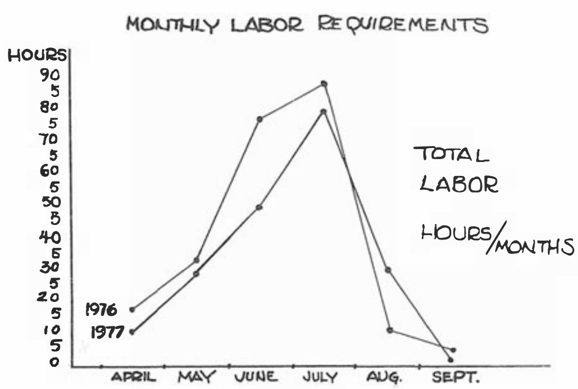


Fig. 2.

shaded out. It was not until the third week in August, after the corn was harvested that they got a chance, but, as a result, produced relatively poorly in terms of edible grams.

Wheat: A small test plot, approximately one-third of a bed, was seeded in spring wheat. Germination and growth were excellent. The heads were big and full by the end of the season. For a variety of reasons, I did not harvest them immediately, the main one being that I had planned to give Earle a sheaf of wheat for our wedding in September. For several weeks they stood in the garden, sturdy and full until the morning I came to pick them and was faced with total devastation. Birds again. Not a grain was left nor a stem unharmed.

Ground Cherries: Ground cherries have a sweet vegetable taste, like a cross between cherries and tomatoes. They are about the size of a small cherry and store easily. We put some in a bucket and left them on a cool back porch. We rediscovered them the following February and most of them were still in fine condition!

A row one foot wide and twenty feet long was planted with ground cherry seedlings that had been started in the small solar greenhouse. Germination and transplanting presented no problems and fruiting was abundant. Due to their novelty, however, few people were willing to put in the time to pick and weigh them or to think of ways to use them. To encourage consumption, reduce waste and lighten the burden of picking for those responsible for the experiment, the weighing ban was lifted. Still, hundreds were wasted on the ground. We are curious to see if any will germinate spontaneously in the garden next year.

Each year a few crops have an unusually hard time, which lowers our overall productivity and efficiency rates. In 1977 the crops mentioned above account for at least 10% failure in the garden. Several other vegetable varieties produced a below average yield but were balanced by those which did extremely well.

Table 2 and Figure 1 give the human labor requirements for the various gardening tasks over the growing season. Figure 2 shows the difference in total human labor requirements between the 1976 and 1977 growing seasons.

Table 3 Water Requirement/Portion.

	1976	1977	
Water in Minutes	3,640	3,151	13.43% decrease of labor required for watering
Water in Gallons	14,560	12,604	13.43% decrease of water required for total production
Amount of Portions Per Gallon Water	0.87	1.25	43.9% increase of water efficiency per portion

Note: It took 1 gallon of water to produce 1¼ servings of vegetables.

Table 3 shows the relation between the amount of water used and productivity in portions of vegetables. In 1977 it took less than one gallon of water to produce one portion of vegetables.

Table 4 shows the relation between the amount of human labor required and productivity in portions of vegetables. In 1977 it took less than one minute of labor to produce one portion of vegetables.

Table 4 Labor Requirement/Portion.

	1976	1977	
No. of Portions	12,715.3	15,781.5	24.1% increase in productivity
Labor in Minutes	14,115.0	12,436.0	11.89% decrease in labor
Amount of Portions Per Minute	.90	1.26	41.0% increase of labor efficiency per portion

Note: It takes 1 minute to grow 1¼ portions of vegetables or it takes less than a minute to grow 1 portion of vegetables.

Table 5 Grains.

	General Information on U.S. Grains.				Food Value of Grains.		Reflection on N.A.I.'s Proposed Diet.				
	Bu./Acre	Bu./1/200th Acre Bed	Lbs./Bu.	Lbs./1/200th Acre Bed	Gr. Protein/ 100 gr.	Cal./100 gr.	Lbs. per/ Year	Gr. per/ Day	Gr. Protein per/Day	Cal. per/ Day	Beds per/ Year
Field Corn	80	0.4	56	22.4	8.9	348	56	69	6.3	248	1
Wheat	30	0.15	60	9	12.3	330	81	100	12.3	330	9
Soybean	25	0.1	60	7.5	34.1	403	40	50	17	201	5.4
Oats	45	0.2	32	7.2	14.2	390	7.2	9			1
Barley	44	0.2	48	10.5	8.2	349	8.2	13			1
Rye	26	0.1	56	5.6	12.1	334	5.6	7	6	348	1
Buckwheat	33	0.16	50	8.2	11.7	335	8.2	10			1
Gr. Sorghum	48	0.2	50	12	11	332	12	15			1
Navy Bean	1156 lb.	--	--	5.7	22.3	340	5.7	7			1
Field Pea	1120 lb.	--	--	8.6	24.1	340	8.6	11			1
Sw. Corn	40	0.2	56	11.2	35	96	11.2	14	4.5	285	1
Popcorn	40	0.2	56	11.2	11.9	362	11.2	14			1
Cane Sorghum	48	0.2	50	12	11	332					
Cane Syrup	400 gal.	2 gal.	--	20 lbs.	--	257	40	50	--	128	2
Potato	20,500 lb.	--	--	102	2.1	76	102	125	2.6	95	1
Alfalfa Seed	--	--	--	--	--	--	--	--	--	--	--
Total							396.9	494	48.7	1635	27.4

DESIGNING FOR A FUTURE SMALL-SCALE FOOD PRODUCING SYSTEM:

Our goal at New Alchemy is to minimize the amount of land needed and to use fossil fuels as wisely and efficiently as possible. Such a system would be complex in terms of technique as in crop rotation, crop succession and companion planting, but simple in skills and tools. We shall have chickens, goats, geese and fish to provide eggs, milk and other forms of animal protein. We plan to concentrate on growing foods which require neither freezing nor canning for winter storage.

Solar greenhouses should prove economical for fresh vegetables. A small family structure could provide the greens for the fall, winter and spring without recourse to fossil fuels. It also provides the space to grow all the seedlings needed for a tenth of an acre garden plot. It would function as an auxiliary heat source when attached to a house.

Land Requirements:

Many new crops will be grown in the '78 season. By using average U. S.-yield figures, we can estimate the amount of land required and hope that, as with the other crops, our yields will exceed those grown on a large scale. Table 5 lists the grains which can be grown to meet dietetic needs and the space required.

Table 6 Goat Milk.

	Annual Feed and Land Required for Average Goat Lactating Nine Months per Year Not Including Pasture or Browse*			Land Required for Producing One Pound of Goat's Milk per Day** per Year
	Pounds per Year	Grams per Day	1/200th Acre Bed per Year	Number of 1/200th Acre Beds per Person per Year
Field Corn	400	493	17.8	4.6
Oats	400	493	55.5	14.6
Wheat	200	246	22.2	5.8
Soybeans	100	123	13.3	3.5
Molasses	75	92	\$***	--
Total	1175	1147	108.8	28.5

* Producing average of five pounds milk per day during lactation.

** One pound goat milk contains 16 grams protein and 260 calories.

*** \$ indicates item purchased.

Table 6 reflects the amount of feed that needs to be grown for a lactating goat. Apart from browse, a goat eats one-half pound of a mixture of grains per day and another half-pound for each pound of milk she produces. The goat is assumed to produce an average of five pounds of milk per day over a nine-month period. The last describes the land requirements, apart from pasture, for an average of two cups or one pound of milk per day per person.

Table 7 Eggs.

	Annual Feed and Land Required for Average Hen Producing 273 Eggs per Year			Land Required for Producing One Egg per Day* per Year
	Pounds per Year	Grams per Day	1/200th Acre Beds per Year	Number of 1/200th Acre Beds per Person per Year
Field Corn	44	54	1.9	2.0
Wheat	7	8	0.7	0.9
Soybeans	9	11	1.2	1.6
Mix (alfalfa, bonemeal, meat-scraps, oyster shell, salt)	10	13	\$**	--
Total	70	86	3.8	4.5

* One egg contains 6 grams protein and 80 calories.

** \$ indicates items purchased.

Table 7 reflects the amount of feed that needs to be grown for a laying hen. A hen is assumed to produce 273 eggs per year. Two chickens per person are included in hypothetical diet calculations. The land re-

Table 8 Land Required for Year's Food Supply with Hypothetical Local Diet.

Food Groups	Grams of Protein Per Person Per Day	Calories Per Person Per Day	1/200th Acre Beds Required
Vegetables	8.0	80	2.0
Grain	48.7	1635	27.4
Goat Milk	16.0	260	28.5
Eggs	9.0	120	6.8
Honey	0.1	150	--
Fruit	0.2	58	2.0
Total	82.0	2303	66.7

quirements for an average of one egg per day per person are shown in the last column of this table.

Based on our vegetable growing experience, we can conclude that two beds will yield a more than ample supply of raw and cooked vegetables for any individual. Producing honey does not require land. A good hive will produce approximately 40 pounds of honey, or 50 grams a day a person. Space is given for fruit as well. The estimate is rough, but a piece of land the size of two beds should support at least a good-sized apple tree and several grape vines. We have computed all this information into Table 8. It is obvious that changes in diet will have an enormous impact on land requirements. Our proposed diet would require 3/10ths of an acre per person.

THE ENERGY RATIO OF OUR EXPERIMENTAL PLOT:

As interest in agricultural energetics is relatively recent, information on the relation between energy and agriculture is still somewhat sparse. In his study, *Energy and Food Production,* G. Leach provided most of the information for performing a preliminary study on the energetics of our experimental garden plot. Garden-sized plots achieve productivity by virtue of inherent small scale and labor intensiveness, which allow for inter-cropping and succession cropping, thus utilizing soil and radiant energy more fully than is possible with monocrop farming. As mechanization has made intensive inter-cropping less efficient, more space is required to grow a single crop. Three times as much land would be necessary to produce the same amount of food by industrial methods as we grew in our garden. Further, in addition to the economic cost of dependence on chemical fertilizers, insensitive treatment of the soil results in heavy losses of topsoil. The U. S. D. A. expects an annual loss of topsoil of up to one inch in shallow soils and up to five inches in deep soils.

The joule (J) is the energy unit used to facilitate the comparison of the different kinds of energy inputs such as labor, machinery, fertilizers and pesticides with each other and with the final energy output in the form of edible food. The joule is a very small quantity. MJ stands for megajoule or 10^6J. The following conversions should give an idea of the meaning of these quantities:

10 MJ = equivalent to 2,400 kcal, the amount of calories of nutrition needed by an average adult per day.

3.6 MJ = equivalent to 1 kilowatt hour (kwh), a lightbulb of 100 w burning for 10 hours.

59 MJ = equivalent to one gallon of gasoline which can move a car approximately 20 miles.

The Energy Ratio (Er) can be found by dividing the edible energy output by the total amount of energy input.

Table 9 Energy Analysis of New Alchemy Experimental Plot.

	MJ/1/10 acre/year
INPUT:	
Labor, 2 x 207 hours at 0.6 MJ/hr.	248.4
Fertilizers, Lime and Greensand, 2 MJ/kg - Light Application of 50 kg each/1/10 acre	200.0
Machinery and Equipment Negligible	--
Total	448.4
OUTPUT:	
35 Vegetables of Total Edible Weight of 1253 kilograms	
Energy Output (Edible Portions)	1672.1
Protein Output (Edible Portions)	22.8 kgP
RATIOS:	
Energy In/Protein	19.6 MJ/kgP
Energy Out/In	Er 3.72

In a comparable study to that in Table 4 done on 600 suburban garden plots in London, England, energy inputs in the form of fossil fuels were considered negligible if they represented less than 10 per cent of the total.

Human Labor: Human labor requires approximately .19 MJ/hr for resting, .29 MJ/hr for small activities, .5 MJ/hr for light work to 1.0 MJ/hr for heavy work. Whereas new gardens with poor soil require a high percentage of heavy work, our established gardens only needed light to moderate labor at .6 MJ/hr.

Journal Four discusses the types of activities included in total human labor requirements, amounting in all to 207 hours over the 1977 growing season. We decided to double this number to account for such activities as working with the spring seedlings, trucking organic matter, harvesting and digging the beds in the fall. Thus, we spent 414 hours of work in the garden; one hour and 22 minutes per day. This is equivalent to 25 per cent of a typical 40-hour work week (414/1714) over a ten-month period.

Fertilizer: We used small quantities of lime and greensand as fertilizers. Extensive soil tests done at the close of the 1977 growing season indicated no further fertilizers would be needed in 1978.

The truck: The truck was the one exception to the exclusive use of such handtools as the shovel, rake, hoe and trowel in working the experimental plot. It was used to pick up organic materials, mainly seaweed and manure, with which we filled in the ditches or pathways between the beds to create strips of sheet compost within the garden. Over the growing season, we made about twenty trips in the truck. Initially, we assumed the proportion of gas to be insignificant in comparison with our total labor input. Some simple calculations proved otherwise. The energy consumed by the truck on forays within a one-kilometer-radius of the farm was equivalent to ten months of human labor.

Energy Output:

We refer here to output of food ready for direct human consumption.

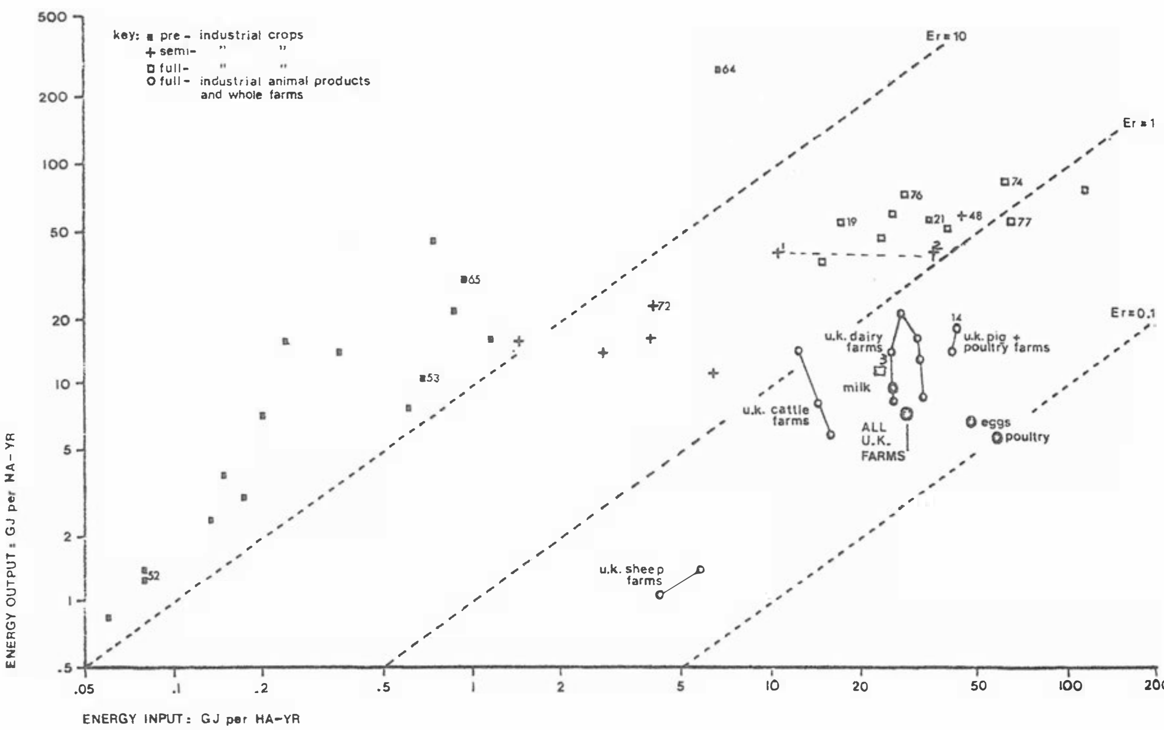
Calories: On 1/10th of an acre, the 1977 garden plot produced the equivalent of about half the energy needs of one person for a year at 10 MJ/day or 2,400 kcal/day. The energy ratio for this production is Er = 3.7 if truck use is not included. Er = 1.0 if the truck is used 20 times for a 6-mile or 10-kilometer round-trip.

Protein: Protein is included in the table. The garden produced the equivalent of all the protein needs for one person for 14 months at 54 gr/day. The energy used to produce this amount of protein was 4 to 16 times less, depending again on the extent to which the truck was used, than the energy used to produce the same amount of protein with industrial farming methods. This difference can be accounted for by the fact that protein derived from industrial farming is mainly from animals, whereas our protein is exclusively from vegetables. It is generally agreed that it takes 9 times as much land to produce a given quantity of protein from animals as it does the same quantity of vegetable protein.

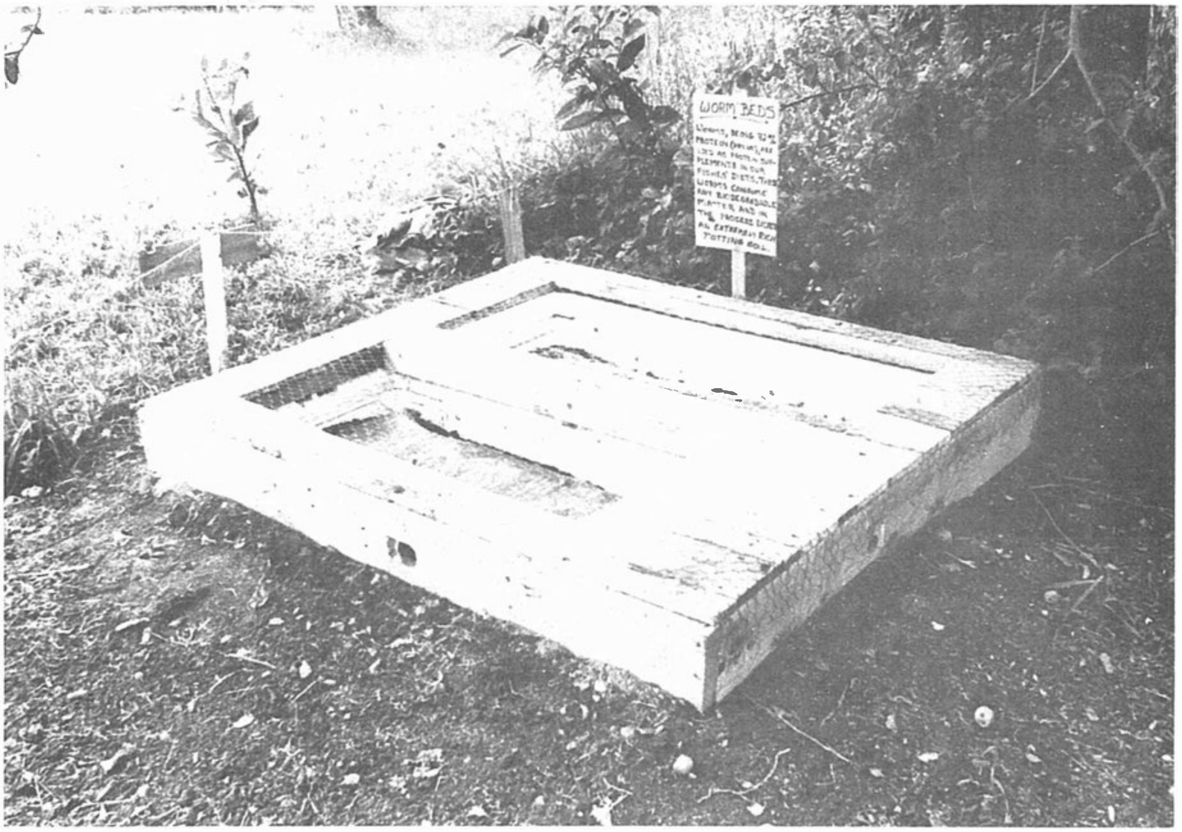
Energy and protein outputs differ considerably with the mixture of vegetables. With the exception of our small crop of potatoes, our vegetable varieties were among the lowest in both calories and protein. Figure 3, again taken from Leach, shows the relationships between different agricultural systems with regard to energy input and output. This graph was used to determine our position in the world food production (+1.-.-.-.-+2). Considering the crops we grew, our position is quite remarkable. None of the other agricultural systems included vegetables. I added the approximate position of industrial vegetable production (□3), which ranks as low in efficiency as cattle and milk production. Vegetables grown in greenhouses, such as greenhouse lettuce with an Er = 0.002, have such a poor energy ratio that they cannot be placed on the chart.

FIG. 3

Energy Inputs and Outputs per Unit of Land Area in Food Production – World



52 New Guinea	- taro, yam, sugar, sweet potato
53 India	- rice, cattle, milk
65 Mexico	- corn by hand
64 China	- rice and beans
72 Philippines	- rice
1 .... 2 NAI	- vegetables
19 UK	- wheat
21 UK	- potato
48 UK	- garden plots - vegetables & 40% potatoes
76 USA	- corn 1970
74 USA	- intensive rice
77 Hong Kong	- rice and vegetables
3 USA (est.aver.)	- vegetables



Some Other Friends of the Earth

– Jeffrey Parkin

"I would not enter on my list of friends,
(Tho' grac'd with polish'd manners and fine sense
Yet wanting sensibility) the man
Who needlessly sets foot upon a worm"

– William Cowper (1784)

I arrived at New Alchemy last winter with the task before me of starting a modest earthworm farm. Many of the people I knew in northern California thought I was joking when I told them why I was leaving there...... frankly, I still smile about it. I knew that growing worms was going to be a unique experience. I had all but forgotten the existence of earthworms since my younger days when I could no longer muster what it took to thread a fish hook through one. By way of contrast, this past spring, summer and fall, I was harvesting our cultured worms at a rate of 300-700 individuals per day.

Each day a writhing mass of worms was fed to designated groups of sunfish, as part of our caging experiments in Grassy Pond (see Page 89). Our economic, ecological and ethical rationale for experimenting with the substitution of earthworms for fish meal which is the principal source of protein in commercial fish feeds is described by Bill McLarney in *Journal Four*. Although they have long been the archetypal fish bait, very little research has been conducted on earthworms as a protein/vitamin source for fish. Our pilot experiments in feeding earthworms to tilapia are detailed in the above-mentioned caging experiments. Suffice to say here, we are very encouraged by the results and are continuing the feeding trials this winter. Beyond their very possible use in fish feeds, the scope of the benefits derived from these lowly creatures is quite extraordinary.

Nathaniel Shaler, a noted Harvard geologist, aptly analogized the thin layer of humus-rich topsoil as "the placenta of life." He cautioned "Man and all

Photo by Ron Zweig

forms of life draw life from the sun, clouds, air, and earth through a tenuous film of topsoil, indispensable, and if rudely handled, impermanent." Charles Darwin devoted a portion of his life to studying the earthworm and its role in the formation of humus-rich topsoil. He concluded his findings in part, "It is a marvelous reflection that the whole of the superficial mould (topsoil) over any such expanse has passed, and will again pass, every few years through the bodies of worms.... It may be doubted whether there are many other animals which have played so important a part in the history of the world, as have these lowly organised creatures." What would cause Darwin to make such a seemingly grandiose statement?

Earthworms spend most of their lives actively burrowing through the ground, all the while ingesting large quantities of organic matter and soil. This ingested material is first, and very importantly, fragmented, which is the initial stage in the cycling of organic matter. Through the digestion process, microbial activity and numbers are enhanced. It is probably microbial activity that accounts for some of the final stages of humification which is the final stage in the decomposition/recycling of organic matter. As much as twenty-four hours after ingestion, the fragmented organic matter is excreted at various levels in the soil, as the feces or casts of the earthworm. The casts are in the form of water-stable aggregates, which can resist erosion or compaction and remain loose whether the soil is wet or dry. Most researchers who have studied mineral nutrients available in both casts and in soils well supplied with worms have reported a higher base-exchange capacity, more exchangeable calcium, magnesium and potassium and more available phosphorus and nitrogen than in soils without worms.

The earthworm thus represents an elegant example of a natural cultivator. Through its routine activities, the earthworm both aerates and improves the moisture-holding capacity of the soil. In addition, these friends of the earth make more mineral nutrients available for plant growth and, through their diligent mixing of the soil, distribute them to the root systems. All these factors are of prime importance to soil fertility. This is evidenced many times in the scientific literature. Hopp and Slater concluded that the addition of live earthworms (four species) consistently increased yields of millet, lima beans, soybeans, hay, clover, grass and wheat. By introducing earthworms *(Allolobophora caliginosa)*, Stockdill and Cossens found pasture production increased by 28% to 100%. Zrazneyski reports (in Russian) that in potting experiments live earthworms increased the growth of two-year-old seedlings of oak *(Quercus rober)* by 26% and of green ash *(Fraxinus pennsylvanica)* by 37%. These are just a few of the studies conducted linking earthworms, improved soil fertility and increased crop yields.

One of the best ways to encourage earthworms in gardens is through somewhat selective mulching. Straw, hay, cardboard, deciduous leaves and/or grass clippings are not only fine mulches, but are also preferred feeds for earthworms. In addition to serving as a source of food, the mulch retains soil moisture, keeps the soil cool in hot weather and provides a cover for the worms from the sunlight, all of which are important in inducing a luxuriant earthworm population.

The scope of the ecological appropriateness of earthworms has relatively recently encompassed biodegradable waste conversion. At New Alchemy we are beginning research on the rate and capacity of "household garbage" consumption by our cultured earthworm, *Eisenia foetida.* When the manure piles are frozen, the earthworms are being fed solely on our household biodegradables. Although data are still being collected, we hope soon to be able to recommend the optimal numbers of worms required to handle specific amounts and types of "household garbage." At the State University of New York at Syracuse, Dr. Roy Hartenstein is conducting the best research I have seen on the utilization of earthworms for sludge management. Not only can worms consume what, at times, can become an environmental pollutant; the end product of their consumption, the casts, is marketable as one of the best potting soils available. Though all of this research appears to have potential, it represents only the beginning of the full realization of its implementation.

While the thought of a basement earthworm garbage-composter may offend some people's olfactory sense, in reality it will not do so. Beyond the brief time required in actually feeding the worms, my nose has never been offended. Most odors are immediately eliminated when the feed is covered with a thin layer of bedding. It is believed that within the first few days earthworms will convert sulfides and organic amines (the major malodorous components) into more neutrally-smelling forms.

Commercially-cultured earthworms are not, generally speaking, the common worms you find in your soil. The two most frequently-reared are *Eisenia foetida* and *Lumbricus rubellus* because of the relative ease with which they can be raised. They require a higher organic (i. e., protein) content in their food than do the more common worms. For this reason, they are better suited to consuming heavy concentrations of almost all types of biodegradable matter, including animal manures, paper products, household garbage and sludge.

I relied upon Gaddie and Douglas' *Earthworms for Ecology and Profit, Volume 1* (reviewed in the fourth *Journal*) for information about culturing earthworms, specifically *E. foetida.* Although this is not an endorsement of all the information in the book, I could not possibly have tested it all (they do have a slight bias toward selling worms). I do encourage anyone interested in growing earthworms to read it. With this in mind, what follows is not intended as a "how to" on worm rearing, but a little basic information and a few of my experiences.

One of my first requirements in culturing the worms was devising a way to contain them. This was especially pertinent since they were to inhabit the basement initially. Considering expense, insulation and lasting quality, I chose large unwanted refrigerators or freezers. To allow for drainage, I laid them on their backs and drilled about one hole per square foot, the holes being just slightly larger than the tubing I intended to use. In an attempt to keep the insulation dry, I caulked sections of tubing into the holes. To prevent the worms from exiting through the tubes, I cemented pieces of nylon stocking over the holes. Another initial requirement was the selection of the bedding, the material in which the worms were to live. Like the feed, the bedding can consist of a wide variety of biodegradable substances. As there is an abundance of riding stables on the Cape, I selected a combination of horse manure, aged beyond the heating stage, and a more ubiquitous substance, cardboard. The earthworms seem to appreciate it. A good bedding should retain moisture and resist compaction. For this reason, soil is not recommended. The bedding may or may not furnish some food.

Basically, there are five environmental parameters that need concern the earthworm grower. The first is temperature. Earthworms exhibit the greatest vitality when their bedding temperature is from 60° to 80°F., with 60° to 70°F. being ideal. By watering the beds selectively with either cold or warm water, I had no problem in maintaining these temperatures. Moisture is another key consideration. The bedding should be kept crumbly moist, not soggy. Sustaining this proper moisture content is essential for best assimilation of the feed by the earthworms. Logically enough, the worms appear most prolific when constantly well-fed. Again, I recommend consulting Gaddie and Douglas for appropriate feeds and feeding methods. Of fundamental concern is the sensitivity of the earthworms to pH. The commercially-reared species seem to prefer an environment with a pH between 6.8 and 7.2. Because most organic matter, especially that high in cellulose and other sugars, tends to become acidic upon decomposition, calcium carbonate (lime) must be added at regular intervals. To aid in proper aeration, the bedding should be kept loose. This is best accomplished by turning over the top three or four inches of bedding every three or four weeks.

It should be fairly evident that growing earthworms does not require a lot of time, formal knowledge or expertise. It does require some care and an interest in them, to which the earthworms respond. Working on a part-time basis, a successful worm grower can manage well over eighty "beds" of worms. Depending on the above-mentioned parameters, in addition to the input of the grower, the earthworm population will double every two to three months. In broad economic terms, in 1976 the total earthworm market had grown to over one billion dollars.

While the two major markets for earthworms are as sportfishing bait and as breeding stock, many others are becoming established. One of the newer ones is as human food. If the growing number of recipes is indicative of increased public acceptance, then earthworms are ending up in more and more people's stomachs. They are billed under such epicurian-sounding recipes as "ver de terre" and "devilled shrimp hors d'oeuvres", as "curried ver de terre and pea souffle" and even, questionably, in "applesauce surprise cake." Mr. Gaddie, a well-known connoisseur, has said, "I must admit, though, they are something of an acquired taste." It is a bit embarrassing to confess that I have never eaten one.

Our main interest in earthworms is their potential link in the process that includes the disposal of organic wastes and the production of high-protein, human food. While the two are intimately linked in nature in the food web, in our civilized societies they are all too often viewed as discrete processes. The earthworm offers a viable means of treating wastes as a valuable resource. According to commercial growers, a successful worm grower with one hundred beds (8'x3'x8"), stocked at optimal density, can expect to harvest 64,000 pounds of worms per year. Dr. Hartenstein's lab has established that worms can process an amount of sludge equivalent to from 0.1 to 0.8 times their own wet body weight daily. Selecting arbitrarily a turnover of twice the weight of the worms, the yearly harvest of this single worm grower would process sixty-four tons of sludge per day. At New Alchemy we are attempting to carry this a step further, encompassing a larger part of the cycle. We are using earthworms as the principal growth component in the diets of fishes. Although these ideas hold promise, I question whether even an elegant biological and/or technological combination exists that will allow us to continue merely covering our tracks. As we become compelled to orient our solutions for the wastefulness of society towards longer-term stability, we should do well to include the earthworm. If nothing (and optimistically more than anything) else, I hope this brings an appreciation of what lies beneath our feet.

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On the Feasibility of a Permanent Agricultural Landscape

– *Earle Barnhart*

I. AN ECOLOGICAL PERSPECTIVE

"In this country you are going to face very big problems about energy, water, and many other things. There is no one single thing I can think of that would be more helpful, and also widen people's horizon or better, particularly city people, than becoming interested in establishing a tree."

– *E. F. Schumacher*
1977
Worthington, Ohio

Self-maintenance of an Ecosystem

In many parts of the world, deserts are advancing into areas that were formerly forests or luxuriant prairies, and eroded waste lands occupy once-fertile valleys. The seven-thousand-year history of human cultures has too often manifested a tendency to obtain materials and energy through heedless exploitation of the accumulated resources of untapped ecosystems. It is evident that ecosystems are the source for all human ecological and economic activities. Even the most powerful nations cannot indefinitely transcend land abuse. Neither governments nor peoples have recognized adequately that the costs for food, clothing and shelter must be paid, not only by the consumer, but by the land from which these necessities come. In chronicling the accelerating destruction of the earth's productivity, Erik Eckholm blames much of the current prevailing poverty of the poor on their ancestors who were responsible for the exhaustion of the resources and fertility of their region. Desertification and erosion are by-products of human agriculture. Yet, even though most destruction of land is humanly caused, it can be most swiftly remedied by decisive human action.

Lest we believe our culture to be more careful than those of the past, agricultural scientist David Pimentel and his associates at Cornell have disclosed that, over the past two centuries, one-third of the topsoil of the United States has been lost. This soil erosion has already reduced American production potential by from ten to fifteen per cent. The Comptroller General of the United States in 1977 conceded that the prevailing system of modern agriculture is associated with an erosion problem of national proportions, one that is being inadequately treated by today's conservation programs. On our present agricultural course, the specter for our children and descendents of a gradual decline of soil fertility and productivity is very real. As a civilization, we are following the same path as many before us, basing our life support on practices antithetical to the patterns of ecological stability and regeneration.

The crux of the problem is that, whereas human cultures have an unusually powerful capacity to intervene in nature, they have virtually no realization of their dependency on its continued well-being. The biosphere is generally conceived, incorrectly, to be one subsystem of a larger socio-economic system. But it is, in fact, the matrix of the forces on which all social systems ultimately depend. The great river of materials and energy that is nature has its own principles and patterns which have evolved into the myriad forms of living systems, including humanity, on the earth. Though not fully understood, the interconnections can be manipulated and directed in our interest. It might be instructive to analyze basic agricultural and social systems in terms of their effect on successful ecosystem patterns in order to illuminate the paradoxical aspects of cultural decisions and to indicate possible alternatives. It is clear that environmental degradation occurs when social systems are out of synchrony with ecosystems.

An overview of our present situation indicates that various forms of land use have become institutionally dichotomized, each with its own limited objectives and its own specialists, often contradictory to one another. For example, foresters consider corn to be the worst enemy of soil, cattle and sheep producers think trees a waste of space and large commercial farmers attribute wildlife to bad luck or faulty spraying. Agricultural and forestry specialists alike must come to see that their crops and forests have functions and outputs beyond food and fiber. Food chains and nutrient cycles exist in nature with or without the human presence. The objective of agriculture is often to maximize a particular product of the ecosystem; a result less noticed is a decrease in efficiency in other parts of the cycles. In an ecosystem not manipulated by humans, a large proportion of the productivity is often involved in self-maintenance or nutrient cycling and in long-term stability as nutrient and energy storage.

Two important components relating to resiliency and survival of an ecosystem are the nutrient and energy stores of the living biomass and the soil reserves. In the humid tropics, most of this storage is within the biomass of the living community. In temperate regions, most of the nutrients are normally within the upper layers of the mineral soil. It is to the benefit of an ecosystem to collect and retain as much nutrient wealth as possible, since minerals can be limited whereas sunlight is permanently renewable. A sloping forest watershed develops a physical structure which results in minimal erosion damage from wind and water. In natural forests many species have the function of gathering or retrieving leached minerals from the subsoil. Dogwood roots retrieve calcium leaching down into subsoils and return it gradually to the surface nutrient cycles. Only small amounts of nutrients are lost from undisturbed forest systems, small enough that rainfall and the normal weathering of subsoil rock can maintain nutrient supplies. Tree canopy and soil control provide water control. Plant leaves absorb the force of rainfall. Soils on forested lands are capable of absorbing one to three inches of rainfall or melted snow per foot of depth without runoff. The water is used by the plants or slowly released to streams and rivers throughout the year. Removal of the forest canopy, as in clearcutting, drastically increases the runoff and erosion, often leading to silting and flooding of rivers and to erratic water supply. One of the major purposes of spending billions of dollars on dams is to make spring flood water available during autumn droughts.

The essential question in the interrelation of human sustenance and the ongoing health of an ecosystem is: how much of the structure and nutrient reserves of an ecosystem can be harvested in perpetuity on an annual basis without degradation. The rate must be determined over a yearly time span since temperate ecosystems store reserves from high summer-production for low winter-production periods. The harvest rate must leave enough to assure continuity of protection and production. The clearest analogy is the management of a beehive for honey. The bees store honey for winter respiration and for spring reproduction. The keeper can remove honey annually only in excess of these needs. Should he remove none, the colony will be stronger and more productive the next year. If he removes too much, the colony cannot reproduce optimally and, at worst, will have insufficient stores for extreme winters. Honey production varies with summer weather and winter needs vary with the severity of weather. To assure survival of the colony, the keeper must harvest conservatively and, in some years, not at all.

In *Fundamentals of Ecology,* Professor Howard Odum analyzes the productivity and stability of various ecosystems. As a general rule, prudent consumers, including humans, should not harvest more than half of the annual net production unless they are prepared to carry out the protective and reproductive processes that nature has evolved to insure long-term continuity. In timber management, more than half of the annual net production can be safely removed only if erosion control and reproduction of the same quality is performed by the forester.

A well-managed forest contains a large standing biomass. The value of sustained yield will range from one to two per cent of the cash value of the entire forest. Consequently, a well-managed forest is always in danger of exploitation. Gordon Robinson, for twenty-seven years chief forester of 70,000 acres in northern California, warns, "We must recognize that good forestry is not a lucrative business. It never was and never will be." Robinson charges that a large portion of the yield in forestry is due to harvesting the accumulated growth of the past and that the U. S. Forest Service and The Bureau of Land Management, by clearcutting areas and by replacing mixed forests with monocrop tree farms, is mismanaging national forests by cutting far in excess of the rate than can be sustained indefinitely.

Clearcutting is visibly degenerative, because of rapid and irreversible soil erosion. Forestry experience shows, in the long run, that mixed-age, mixed-species management keeps forests producing permanently with least human energy inputs and without seriously disturbing soil quality, water control and wildlife. A monocrop tree farm, on the other hand, with highly specialized demands for certain nutrients from a fairly uniform soil level, is more prone to insect and disease problems and has high management costs for forest planting and pest control – functions performed in nature by the ecosystem.

Another essential feature in the structure of every permanent, natural ecosystem is the regulatory animals which graze, recycle and pollinate the plant life and prey upon each other. Native North American woodlands formerly contained an enormous complexity of animal species, including highly diverse invertebrates (mainly insects and spiders), herbivorous and predatory birds (nesting birds, turkeys, owls, hawks) and herbivorous and predatory mammals (squirrel, deer, elk, foxes, bears and mountain lions). These animals lived within the environmental protection of the forest, consuming some of the net annual productivity while cycling materials, dispersing seeds, consuming diseased plants and pollinating, and performing numerous other maintenance functions. In general, herbivore species cycled materials and predatory species regulated the herbivores.

The physical structure of the forest (tree trunks, limbs, leaves, dense shrubs, streams) provides shelter for regulatory animals. Microclimates of wind, air temperature, relative humidity, depth of snow and soil moisture protect the animals from environmental extremes. Over time, natural communities evolve to utilize annual pulses of energy and accumulate structural biomass which protects soil surface and regulatory animals from environmental extremes of wind, precipitation and temperature.

Human Intervention in Ecosystems

Conventional forestry management ranges from periodically removing the largest timber trees ("survival of the stunted") to arbitrarily selecting the seedlings to be allowed to mature (selective thinning), to clearcutting small areas in order to encourage herbaceous growth as food for useful wildlife (such as deer or game birds). In each case, human-directed energy is used to influence the proportions of plant species. The harvested material, whether wood or food, is removed from the system. If the biomass removed is a fraction of the annual net productivity, structural stability is maintained. New patterns of regulatory animal relationships are created, based on the changed flora. For example, existing regulatory links may be removed by destroying potential food or habitat elements such as nesting sites or animal dens. If the animals eliminated are predators, herbivore grazing will increase. Insect damage or overbrowsing by deer can result. People must substitute for the work of the regulatory link which they have eliminated.

A more far-reaching intervention is to favor grazing in a forest intentionally, either by deer or cattle (or both). In this case, wild predators are eliminated and grazing animals increase in numbers and in the proportion of plant biomass they consume. Removal of wild predators and continuous grazing will retard reproduction of food plants, allow reproduction of non-food plants and eventually stabilize the proportions of the grazing food chain within the system. Usually, to sustain the grazing food chain for their benefit, people must either (1) take over the task of predator, (2) replace a selective grazer with a non-selective grazer, which can eat anything, or (3) aid in the reproduction of wild food plants or introduce and protect new ones, for example, by creating pasture land. Each of these options can be carefully done, but usually are not. Over-grazing commonly drives the ecosystem toward rough shrubs or open pasture, depending upon the forest type. In the worst cases, as pastures decline in quality, sheep replace cattle and then goats replace sheep. In any of the processes, direct removal of 30 to 50 per cent of the annual plant growth will reduce the ability

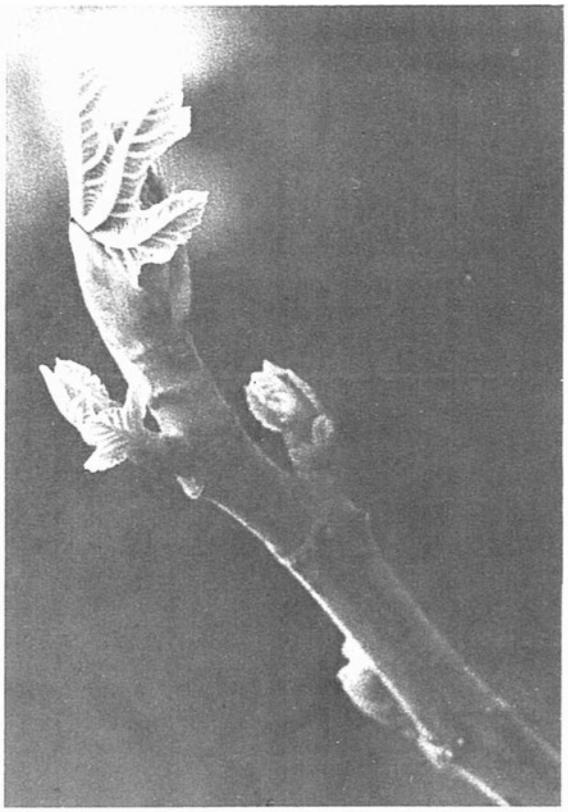

Photo by Hilde Maingay

of the ecosystem to resist environmental stress. Wildlife populations are eliminated, soil compaction occurs and sod cover slowly develops. A simplified community is left in which plant productivity passes to humans through a short food chain. The grazing animal does a good deal of the nutrient cycling work for the ecosystem. Roughly half of its food input is returned to the soil as feces. But the standing biomass of the ecosystem and regulatory animals are reduced, erosion is increased, nutrients are exported as human food and auxiliary energy must regularly be used to maintain pasture plants against invading competitors.

A more sound variation in an ecological sense of the woodland/pasture ecosystem is a combination of fruit trees in a pasture surrounded by hedges or shelter belts. The orchard and windbreak plants simultaneously provide environmental protection from wind and rain damage, human food from the orchard and wildlife habitat in the shelter belt for regulatory animals. The pasture grass protects the soil surface and is permanent if grazed conservatively. Shelter belts protecting orchards have been shown to improve crop yields by favorably affecting wind, humidity, winter soil temperatures and pollination. The best microclimates and yields occur in an open, permeable windbreak structure. Increased production more than makes up for the one to four per cent land used and the costs incurred.

Agriculture Energetics

The gross productivity of managed ecosystems does not exceed that of natural systems. Human management is primarily a process of channeling a greater proportion of the productivity into forms we can use for food and materials. Many primitive subsistence agricultures in mature forest ecosystems yield five to twenty times as much food as in relation to energy used in the process. By planting a small area within the mature system to domestic species, the existing benefits of environmental protection and animal regulation of crops are derived. The proportion of food output to the overall forest ecosystem is low, but the larger ecosystem performs much of the regeneration. Such methods are sustainable indefinitely, obtaining energy almost entirely from the land itself.

Modern annual crops such as grains and vegetables and modern domestic animals convert a large proportion of growth into useable food. They are domesticated in the sense that they no longer have built-in mechanisms to survive in harsh environments or natural competition. Large amounts of energy in the form of the work of the farmer are used for protection and reproduction, while the energy of the crops goes into food products.

In the labor-intensive agriculture of China, much of the protection, nutrient cycling and regulation that occurs in a natural ecosystem is performed manually. In return, almost all of the output of the agriculture is part of the human food chain.

A Redesign of Agriculture

A review of agriculture indicates that it has been, in the main, destructive in its disregard for fundamental ecological processes of regeneration and long-term soil stability. However, in some cases, sophisticated use of small amounts of energy to manipulate an ecosystem for agricultural purposes can be efficient and permanently successful. The quantity of energy used is not as important as the way in which it is used, but any energy used wisely can yield a return. The real question is not whether but how to alter ecosystems with energy. If humanity is to restore and reconstruct the earth, we shall have to begin by rethinking agriculture and landscapes. At New Alchemy we are interested in re-integrating existing knowledge of traditional farming methods with fundamental ecological principles.

In the highly simplified ecosystems created by industrial agriculture, the farmer uses large amounts of fossil fuel to perform the survival functions of the plant and the protective functions of a natural ecosystem. Soil fertility and stability are maintained by adding fertilizer, crops are protected from insect and animal predators with pesticides and fences, weather extremes are minimized by irrigation. Seed production, seed storage and planting for annual reproduction are carefully manipulated. Nonetheless, crop nutrients are lost from the system. Employment of fossil fuel, fertilizers, chemicals and machines can double or triple the output per acre or output per work-hour on the land, but this practice often consumes many times more energy than is returned by the crop. Even with high energy input, such techniques cannot duplicate the protection of soil conservation and soil fertility in a natural ecosystem. The rates of erosion from current agricultural practices do not portend well for the future. The equivalent of five gallons of fossil fuel per acre is required to maintain production in the face of erosion.

The need is to generate new agricultures which would mirror the workings of nature, using renewable energy and appropriate technology to insure reasonable productivity and environmental permanence. Agricultural alternatives must be broadened.

Odum has suggested guidelines for such alternatives. A natural landscape is rather like a patchwork of communities of varying ecological ages. Occasionally local disturbances such as storms, floods, fire or disease will drive some areas backward toward simpler or younger stages which have a high net productivity but less regenerative resilience. The goal is to create overall agricultural landscapes which exhibit the same form and function, yet benefit society. Such landscape patterns would be an integrated patchwork of "young" and mature or stable zones, carefully combined for environmental protection, food production and animal regulation.

The general limits of the ecosystem would be determined biogeographically, simulating naturally-occurring, climatic climax communities. The agricultural landscape for an American eastern forest biogeographic province would be different to that of the central plains region. The biotic components would be chosen to include climatically-adapted multiple-use plants and animals, both wild and domestic. The structural and appropriate technological components would have to complement and reinforce the biological function. Nutrients would be retained and accumulated within such a system.

Ecological Islands

Scientists investigating ecological theory are beginning to evolve general laws and mathematical models of the functioning of ecosystems. One interesting area of study is that of species equilibrium on islands. Kolata reviews a model describing how island species (which can be understood to refer to either a real island or a biological island, such as a national park or greenhouse) maintain continuous equilibrium between immigrations of other species and the extinction of indigenous species. What is significant is that, when a protective island is created in nature, species migrate to it spontaneously and establish unique, new communities. As periodic extinctions and new introductions select for mutually-adapted species, such new communities organize themselves over time. It is conceivable that in relatively undisturbed, protected habitats, like the hedges and windbreaks in English landscapes, this type of process occurs around agricultural systems and that the wild species involved develop a symbiotic interaction with the agricultural species. In England, a large percentage of wildlife species are found only when they are protected by hedges, and hedge communities are known to harbor a great diversity of insects, birds and mammals including pests, predators and pollinators. Before the widespread use of pesticides, forest and orchard managers made conscious efforts to provide habitats for and to encourage birds and parasitic insects as a primary check on destructive insects.

An agricultural landscape incorporating the interactions of mixed-age agricultural zones or ecological islands would include at least four basic functional types:

Protective elements, in which permanent plant communities act to moderate forces of wind and water to prevent erosion.

Productive elements, the grain fields and gardens, meadows and orchards, intensively managed for food production.

Regulatory animal habitats, plant communities or physical structures which provide shelter and food for useful animal species such as predators, parasites and pollinators.

Nutrient cycling elements, species or communities which strategically retrieve leaching nutrients, fix atmospheric nitrogen or convert waste products from other zones (such as human wastes) into nutrients useable for fertilization.

Odum would add a zone called "urban-industrial" and also "multiple-use." I contend that the urban-industrial elements should be as diverse as possible and that each suggested category is, by nature, multi-functional.

Several implications of such a synthesis should be noted. The primary impetus is to insure permanent high levels of biological productivity. Soil erosion is the greatest single threat to biological productivity, yet the time-scale is often so long that degradation can go unnoticed within a human generation. Many of the farmers who experienced the American dust-bowl and took action to halt it are gone, and younger farmers have not fully internalized the necessity for soil care. Protection against such ecosystem dynamics as slow erosion, which have generation-long feedback times, must be institutionalized, as exemplified by terracing in China, to insure generation-long stability. Short-term feedback regulation such as pest outbreaks are less difficult to affect in mixed ecological landscapes, since predatory response can be closer, more constant and more precise than after-the-fact application of pesticides.

Species used as ecosystem components display varying degrees of food productivity, environmental resilience and self-protection depending upon their degree of domestication. It is beneficial to select species with a favorable combination of these qualities for initial use in experimental landscapes.

In studying natural and agricultural plant communities, ecologists have discovered that there are, in each of them, optimal proportions of total leaf surface to ground area. In mature forests, a common leaf surface to ground area ratio of up to ten maximizes gross production for biomass maintenance, but for agricultural crops a ratio of four yields maximum net harvestable production. These relationships can be used to create zones or combinations of zones of such proportions as to reach a productive but sustainable level for each biogeographical region.

Some Available Biotic Components and Integrative Knowledge

Consideration should be given to natural climatic climax vegetation in a long-term biological community. Udvardy's *A Classification of the Biogeographic Provinces of the World* is an introduction to the major vegetation zones of the earth. Another source of information is the knowledge and use of native vegetation by indigenous peoples. Of the more than three thousand plant species used for food, only three hundred are currently grown widely and twelve of them furnish ninety per cent of the world's food. The North American Indians made use of over two thousand native plants and a wide variety of animals.

Photo by Hilde Maingay

Plant Resources

In a biological community, native tree species should be given first priority as protective elements, as they are likely to be adapted climatically. Dr. Stephen Manley, a forest geneticist on Prince Edward Island, is reestablishing and recovering almost-extinct hardwood species for timber. In Pennsylvania, William G. Jones, a reforestation specialist, has a test area consisting of more than one hundred and twenty different species of selected trees and game-food shrubs. Tree seeds for hundreds of species are available from Herbst Brothers Seedsmen, Inc., in Brewster, New York. Information on perennial plants for wildlife food is available from forestry texts and horticultural literature.

Perennial food plants for agriculture range from edible roots to nut trees. Valuable information sources include the Northern Nut Growers Association, specializing in improved varieties of nut trees, the North American Fruit Explorers, who systematically test improved fruits and berries for food production, the International Association for Education, Development and Distribution of Lesser Known Food Plants and Trees, which explores native and exotic minor food plants, and the Henry Doubleday Research Association of England, which is proposing to form an international tree farming institute. *Tree Crops* by J. Russel Smith and *Forest Farming* by J. Sholto Douglas and Robert A. de J. Hart are invaluable sources in the literature. Scions from antique apple orchard trees are available from the Worcester County Horticultural Society, Massachusetts, and improved disease-resistant fruit varieties for testing are available from the New York State Fruit Testing Cooperative Association in Geneva, New York. Government and commercial nurseries carry many standard varieties.

Animal Resources

Many domestic animals used today were bred from earlier, hardier, more self-reliant stock. The older strains are better suited to agricultural systems that demand less energy input. The American Minor Breeds Conservancy Inc., the Society for the Preservation of Poultry Antiquities and the Rare Breeds Society have information on the remaining populations of special-purpose and regionally-adapted varieties of cattle, sheep, goats, swine, horses and fowl.

Pollinating insects have long been recognized by biologists to be important components of ecosystems, yet farmers often consider pollination to be a phenomenon that will occur without any effort on their part. This may have been true in the past, with at least five thousand species of wild bees in North America. But recent intensive cultivation has eliminated habitat and food sources for bees, and pest control has killed them directly so that, in many regions of the world today, there are not enough pollinators for proper pollination of crops. USDA entomologists estimate that the value of honey bee colonies to the crops around them is roughly one hundred times as much as the value of the honey. As for efficiency, one colony of honey bees pollinating cucumbers can replace three hundred laborers.

Bees require season-long nectar and pollen sources, usually from wild flowers, to maintain their strength between main crop periods. Apiculture literature lists the most beneficial plants for bees in various regions and seasons. Parasitic hymenoptera, which control pests in crops, also require wild flowers through the season. Populations of these wasps are highest in crops near such food sources.

Traditionally farmers have kept only honey bee colonies *(Apis mellifera* L.) for pollination and honey. Recently in the western United States, alfalfa farmers have begun to culture the alkali bee *(Nomia melanderi* Cockerell) and the leaf-cutter bee *(Megachile pacifica* Panzer) in their fields. Even bumble bees are excellent pollinators, but they have been largely eliminated by the destruction of suitable habitat.

Birds are often overlooked as insect control agents. In 1905, the Massachusetts Board of Agriculture published *Useful Birds and Their Protection*, a resource book for farmers on how to attract and protect birds that are effective predators on crop pests. Forbush, the state ornithologist who assembled the book, asserted that an acquaintance with the useful birds on a farm is as important to farmers as is a knowledge of the insect pests which attack their crops. Forbush stated, "The position of birds in nature is a swift-moving police force to correct disturbances caused by abnormal outbreaks of insect life." An ample bird population will keep down insect outbreaks in forests as well. In European woods, some dead trees are left standing as habitats and bird houses are provided to foster birds.

Work in Progress

Interesting examples of ecological design abound. The Russians have created shelter belts which can optimize either snow distribution or wind reduction. General experiments have indicated that yields of grains, pasture and fruit increase proportionately to the height of the belt. Specific design involves the proportion of land given over to shelter belts, typically one point eight to four per cent, and the permeability of gaps in the windbreak. Interestingly, twenty-five to thirty per cent permeability is optimal for grain yields. The Russians also find that broad-leaved shelter belts in the leafless winter state gave an average lee effect of thirty-six per cent. In the steppe region, ten to fifteen per cent of fruit-bearing trees are used.

Multiple-story crops employ trees as the upper level. In *Farmers of Forty Centuries*, Professor F. H. King describes a Japanese peach orchard with thirteen rows of vegetables between each tree row. Closer to home, Hollis Lovell of Cape Cod has transformed a steep,

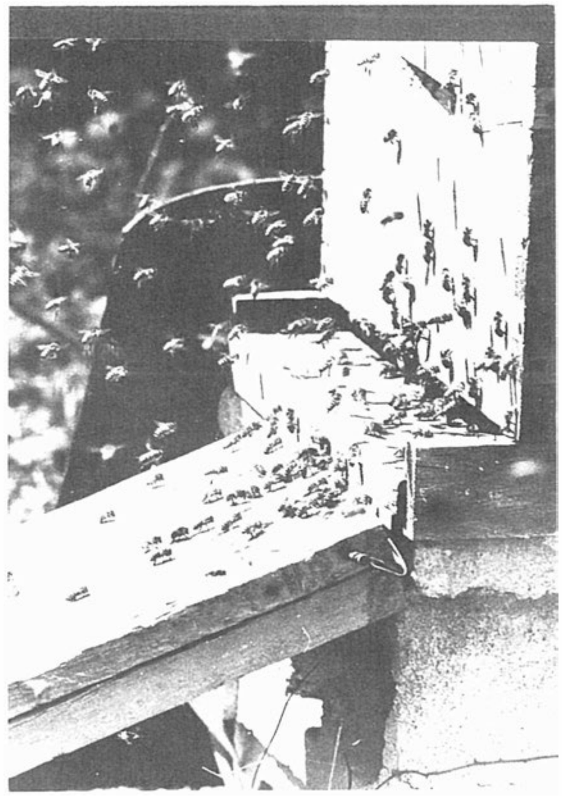

Photo by Hilde Maingay

rocky woodland into a mixed fruit orchard interplanted with dozens of types of berries, vegetables and flowers. His productive farm is on land classified as "unarable" on soil maps. In Missouri, a walnut/soy bean/wheat system has been tested for several years. Preliminary results indicate that the ground crops yield ten per cent below normal, proportionate to the surface area occupied by the trees. New Zealand farmers on the North Island combine large plantations of Monterey Pine *(Pinus radiata)* with cattle on permanent pasture below. And, in some areas of Africa, farmers have adopted mixed perennial crops (bananas, coffee and other trees) with short-cycle crops to ensure that the amount of growing biomass will not drop below a critical level.

It is painfully apparent that conservation slogans without effective economic incentives have little benefit, but perhaps the shortcoming lies in our overly-simplistic economic accounting system. How, for example, does one calculate the benefits of a windbreak which, over time, increases property values from five to twenty per cent in residential aesthetics, reduces air conditioning loads and heat loss on fuel use by twenty to thirty per cent and costs less but outlasts a steel fence by sixty years, producing wood and pest protection all the while. Would a bank loan officer be swayed when normal accounting shows that annual return on investment for commercial forestry is only 2.5% to 3.5%? And what incentive is there for a beekeeper to increase crop yields throughout the agricultural and natural community by more than a hundred-fold the value of his honey, on which he may, on the average, just break even? If profits from high agricultural net yields do not contribute significantly to the maintenance and regeneration of the ecosystem, then that production is destructive.

Economic theorists might give some thought to the implications of an economics that is cyclical and synergistic rather than one that is linear and synonymous with waste. We must extend the concept of life-cycle costing to the life-cycle of the biosphere. In microcosm as in macrocosm, plants, farms and landscapes must be attributed a value relative to their role as sustainers of permanence.

II. DESIGN GUIDELINES

Dedicated to Elzeard Bouffier – shepherd, beekeeper - and the man who planted trees

Elzeard Bouffier was an almost mythical figure who, by systematically planting trees, slowly but completely transformed the landscape of a hilly, waste area of Southern France into a strong, productive forest ecosystem. Over time, as he worked, streams and springs reappeared, animal wildlife flourished again and people returned and formed communities. He exemplifies the restorative powers of a single person who understands how to direct biological forces gently but effectively.

Biotic Resources and Values

Almost all food and energy on Cape Cod is imported at the expense of environmental quality elsewhere. Yet biological resources and examples of local agriculture are available, indicating the potentiality for reconstructive approaches to food and energy. Locally-adapted antique fruit trees, nitrogen-fixing shrubs, productive biological gardens requiring no pesticides or commercial fertilizers and a variety of food plants and trees are components of an agricultural landscape available to us. The sun, soils, rains and winds are the substrate for our design.

Cropping systems incorporating a variety of perennials (nuts, fruits, herbs) that would utilize a site without soil disturbance have yet to be developed, though some have been proposed. Ken Kern describes an orchard system that is started with a mixture of food annuals, berries, dwarf fruits and standard fruit and nut trees. From the start, some food is produced each year, but the annuals and small fruits are slowly shaded and phased out as permanent trees begin to bear. The principles in this idea are excellent but overly-simplified in terms of ecological process.

In a permanent agriculture, the primary values must be those of natural ecosystems: conservation of soil and nutrients, control of water, high average gross productivity, herbivore regulation and cycling of nutrients. The secondary values, important to management of the process, are minimal capital

Photo by Ron Zweig

expense, cumulative skill acquisition, annual distribution of labor and relatively stable production of food and materials, accompanied throughout by increasing ecological stability. Net monetary profit is low initially as net productivity is reinvested in the ecosystem. Gross productivity increases over time.

Many of these values are dependent on the plant species chosen. As a general rule, native species and mature, existing vegetation are most likely to be adapted to indigenous climate, disease and soil conditions. Particular effort should be made to locate fruit and nut trees and other food plants which are either native or domestic remnants of the era preceding industrial agriculture. These individuals retain such qualities as temperature hardiness, proven productivity and other values for which they were formerly selected. These plants, which often can be traced with help from elderly residents, should be propagated for major perennial crops.

Native, nitrogen-fixing shrubs are important in nutrient cycling. On Cape Cod, useful species are bayberry *(Myrica pensylvanica),* Scotch broom *(Cytisus scoparius)* and black locust *(Robinia acacia).* At least one hundred and eighteen species of root-nodulated, nitrogen-fixing plants, exclusive of the legumes, are known to exist. Plants which provide habitat or food for wildlife, pollinators, birds and insect predators should be identified. In our area, staghorn sumac *(Rhus typhina)* produces dark red berries used by ninety-three bird species. Red cedar *(Juniperus virginiana)* nurtures thirty-nine species, autumn olive *(Elaegnus umbellata)* twenty-five species, and bayberries are used by seventy-three bird species. The plants of an area set the biological conditions for the animal species that become established.

Significant ecological cohesiveness emerges when single species of plants perform two or more functions simultaneously, as with the bayberry which is both nitrogen-fixing and a food source for regulatory birds. The primary design goal is to integrate new communities of plants, each of which performs the multiple-functions of environmental protection, food and material production, habitat for regulatory animals and conservation and cycling of nutrients. These functions will vary proportionally with each plant and total proportions with the age of the agricultural landscape.

A simple example of a tree with multiple functions within the agricultural system is the black locust which fixes nitrogen, creates an open canopy over pasture, produces nectar for bees, is a source of durable wood for construction and is excellent for fuel. Another example is the various willows (*Salix* sp.) which are easy to propagate, are used in erosion control, can be planted for livestock-proof "living fences", and annually produce willow rods for woven containers or woven fences. When allowed to grow, they become a coppice system supplying annual harvests of garden poles or firewood, all the while producing pollen for bees and a habitat for insect-eating warblers.

New Alchemy has started an arboretum of potentially-useful species for creating agricultural landscapes. We are collecting disease-and-pest-resistant varieties of fruit and nut trees, particularly antique varieties (apples, pears, mulberries, beach plums *(Prunus maritima),* Chinese chestnuts, black and Carpathian chestnuts, heartnuts, hazelnuts, beech and oak). We have planted dozens of varieties of commercial fruits not currently grown on the Cape for testing (varieties of pears, peaches, plums, cherries, apricots and persimmons). Other important native plants such as Scotch broom, Japanese or beach rose, elderberry and introduced plants such as willows and honey locust have been gathered. These are being incorporated into the landscape of our gardens, fields, bioshelter windbreaks and solar courtyards. They are part of a long-range observation and testing program for growth rates, responses to mulching, fruiting schedules and productivity and amenability to propagation and grafting. Some plants and seedlings are being grown as rootstock for subsequent top-grafting to superior strains. We plan to graft thornless honey locust to J. Russel Smith's "Millwood" honey locust for animal fodder production, apple rootstock to local antique apples and Nanking cherry rootstock to local peaches to produce espaliered dwarf peach.

Agricultural Landscape Design

To test ecological concepts in agriculture, experimental food systems must be carefully designed and monitored for effectiveness. Relative proportions of protective, productive, regulatory and nutrient-cycling elements must be derived empirically from known ecosystems using the best knowledge and concepts available. Until now, permanent agriculture has been more of an art than a science, and we are painfully aware of its limitations. The gradual selection of successful restorative forms is a task of generations, taking as long perhaps as the exploitation which engendered it. "It takes some time if you embark on a long journey", said Schumacher, "and the only advice that one can give is that you should get up early."

Proportions, Geometry and Synergisms

Within the past decade, foresters at Yale have created a simulation model of thirteen tree species of the northeastern United States. By using known relationships of growth rates, climate and soil and basic competition effects, they have been able to depict accurately the development and change in forest communities over long time periods. Within the model, hypothetical logging at an arbitrary point in time will result in changes in species and growth similar to those changes occurring in nature. But, apart from a very few tree and crop species, we currently have little of the knowledge needed for similar modelling of more complex systems. The basic relationships and compatibilities for new agriculture will come from many experiments and close observation. An experienced forester or ecologist drawing on cumulative experience can produce predictions comparable to the Yale forestry simulation. Initially, we must draw on whatever accumulated knowledge of natural patterns is available.

Broadly considered, the critical variables of design in any location are the relative proportions of space allocated to protective, regulatory, productive and nutrient-cycling zones, and the percentage of net primary productivity removed annually from each zone. We have a few approximate values for the protective and regulatory functions. Optimum benefit from wind protection occurs when one to four per cent of the acreage is in permeable shelter belts. Erosion control calls for terracing or permanent vegetation on slopes steeper than eight per cent. As for pollination, standard practice in commercial orchards is to have one strong hive per acre. Optimum fruit-tree cross-pollination occurs when one out of five evenly-distributed trees is a different variety. All soil conservation practices such as windbreaks, sod waterways, hedges and stream bank vegetation are known to be favorable to wildlife, vegetative cover being the basic source of food and protection. Bird habitat and nesting sites are simultaneously fostered. Other accepted woodland management practices specific to wildlife call for three to four animal dens per acre, two to three protective brush piles per acre, five to fifteen per cent of an area in wildlife food plants and a fifteen to twenty foot shrub zone between woodlands and fields. Combining windbreak functions with wildlife food plants and assuming the substitution of domestic animals for larger wildlife, the protection/pollination/regulation area required may tentatively be limited to five to ten per cent.

The remaining production and nutrient-cycling areas must be managed for sustainable yields of food and materials. Odum states that, in a natural ecosystem, with no human management or auxiliary energy inputs, the biotic community seems to require fifty to seventy per cent of net annual primary productivity to maintain current levels of environmental stability. If none of the net biomass is removed, the ecosystem stores energy and nutrients in the biomass. Several distinct agricultural strategies have been developed to harvest the net yield:

1. Multi-annual harvesting of accumulated food, after which the wild ecosystem regenerates without intervention (e. g., hunting, gathering)
2. Annual harvesting of accumulated net increase, with unassisted regeneration (e. g., pastures, herding, orchards, wild and domestic perennials)
3. Multi-annual harvesting of accumulated food, after which the ecosystem regenerates with human intervention (e. g., slash and burn, forestry, fallow lands)

Among these harvesting strategies the energy-efficiency ratio, energy-labor productivity and food-energy-per-unit-of-land can vary by more than one thousand. The quantity of energy input is less important than how and when it is used. Efficiencies do not necessarily indicate the sustainability of methods over time.

Odum's findings imply that, if a farmer is able to select highly productive strains of crops and animals and to use energy to maintain them, more of the net productivity can be harvested as food. The maintenance work involves assuring reproduction, protection from predators and the recycling of nutrients. If auxiliary energy is effectively used to maintain domestic species while assuring the continuity of basic ecosystem functions, a productive permanent agriculture is possible. Outstanding examples are Chinese and Indonesian small-scale polyculture in which human and animal labor are integrated with land and energy. Chinese production strategies are well worth incorporating into new models.

Important Chinese strategies include:

1. Almost total conservation of nutrients and soil on the farm site.
2. Rapid cycling of wastes within it.
3. A high degree of water control and use.
4. Intensive polyculture plots of legumes, vegetables, grains and fruits, maintaining near-constant plant cover.
5. Domestic animals to convert waste vegetation into edible protein and manure for fertilizer.

A critical factor is a size-scale small enough both to monitor closely and to facilitate transfer of the wastes and nutrients quickly from one part of the farm to another.

Experimental Farms for Cape Cod

New Alchemy has developed a number of ecologically-derived food production processes for small-scale agriculture which could be used as components in an integrated agricultural landscape. These include intensive vegetable gardens, aquatic ecosystems for fish production, passive solar greenhouses and bioshelters for propagation and winter food production, and sail-wing windmills for irrigation. We are extending the scope of our agriculture to include field crops, tree crops, ponds, agricultural forests and terrestrial animals into more highly-integrated landscapes. Initial experiments will consist of selection and evaluation of biota, stressing local hardiness, ease and speed of propagation and rates of growth. Plants and animals will be tested for ecological compatibility in such combinations as

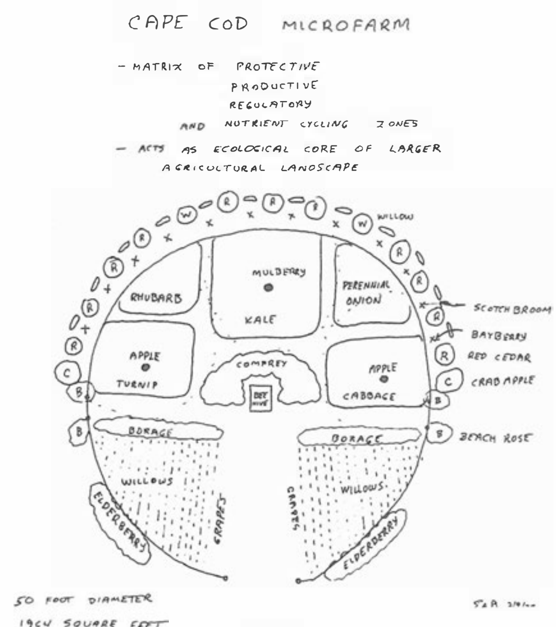

Fig. 1

Photo by Hilde Maingay

rapid local cycling of plant and animal wastes into food chains, increasing ecological stability over time and multiple-function of each component. Particular emphasis will be towards self-regulation and maximum benefits from inputs of auxiliary energy.

The design of an ecological agriculture necessitates relatively complex, successional processes. Figure 1 is the initial stage in the creation of such an agricultural landscape. It is composed of a mixture of protective, productive, nutrient cycling and regulatory elements which together create a small-scale ecological unit. The core develops as an intensive micro-farm supplying vegetables, fruit, honey, materials and firewood, but is designed to undergo succession as an ecological island in a larger-scale agricultural plan, generating habitats for pest-control species and materials for expansion. The areas for expansion incorporate tree crops and animal husbandry in low-maintenance combinations. The eventual extension of the agricultural landscape would include woodland, orchard, pasture and field-crop zones.

The micro-farm in Figure 1 is designed for agriculture on the flat, sandy soils of Cape Cod. The design emphasizes perennial plants which can be transplanted from local sources for very quick but permanent establishment of the plant community. Major functional zones are:

North shelter belt of conifers and nitrogen-fixing shrubs, for wind protection, food and habitat for regulatory animals with interspersed minor food shrubs.

Food production zones employing non-perishable vegetables.

Multi-use materials production, in this case willows *(Salix purpurea* and *Salix vitellina)* supplying cuttings for baskets, garden ties and poles, "living fence" rods for further fencing eventually becoming a coppice for firewood.

Miscellaneous herbs and shrubs for minor foods for people, bees and wildlife.

Bee hive for local pollination and honey production. Additional bee colonies may be added with expansion.

Fertilization must replace nutrients lost in food harvesting. External supplies of leaves and seaweed will be used to mulch the trees and shrubs, while prunings, plant wastes and clippings of nitrogen-fixing shrubs will be composted for use on the food production plots.

Figure 2 explores two possible modes of expansion to tree crops using domestic animals for weed control

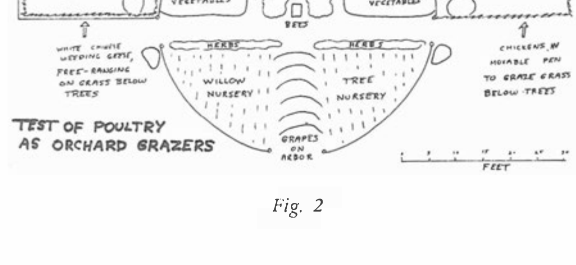

Fig. 2

and meat production simultaneously. One option places "weeding geese" with mixed young fruit and nut trees with nitrogen-fixing shrubs in a fenced area. The other uses a moveable pen of laying hens to weed a similar tree crop area selectively. As tree crops become mature, forage can be grown among them for mulch and cut as hay for animals. A larger shelter belt of mixed timber trees protects the north perimeter.

A fundamental task of New Alchemy is the search for ways to replace the excessive energy and hardware used by our culture with knowledge from nature to achieve the permanent sustenance of communities. We propose that basic community needs can and should be sustained regionally, realizing landscape to be not merely a source for production but a permanent matrix of environmental protection. Toward that end, we have begun to develop solutions that can be used by individuals or small groups in the forms of ecologically-derived kinds of energy, agriculture, aquaculture and housing.

As this *Journal* goes to press, we have just received a new and outstanding work which eclipses all previous treatments of agricultural forestry as permanent support for human cultures. *Perma-Culture, A Perennial Agriculture for Human Settlements,* by Bill Mollison and David Holmgren, is a masterpiece of synthesis in the design of ecologically-derived landscapes and agriculture for the region of Tasmania in Australia. This book is unquestionably destined to become the handbook and pattern for similar designed ecosystems in other bioregions. Indeed, Tasmania is similar enough in climate to Cape Cod to make it a valuable working model for us.

"We do not believe that a society can survive if it lacks values, direction, and ethics, and thus relinquishes control over its future destiny. This book is a contribution to the taking of such control."

from *Perma-Culture*
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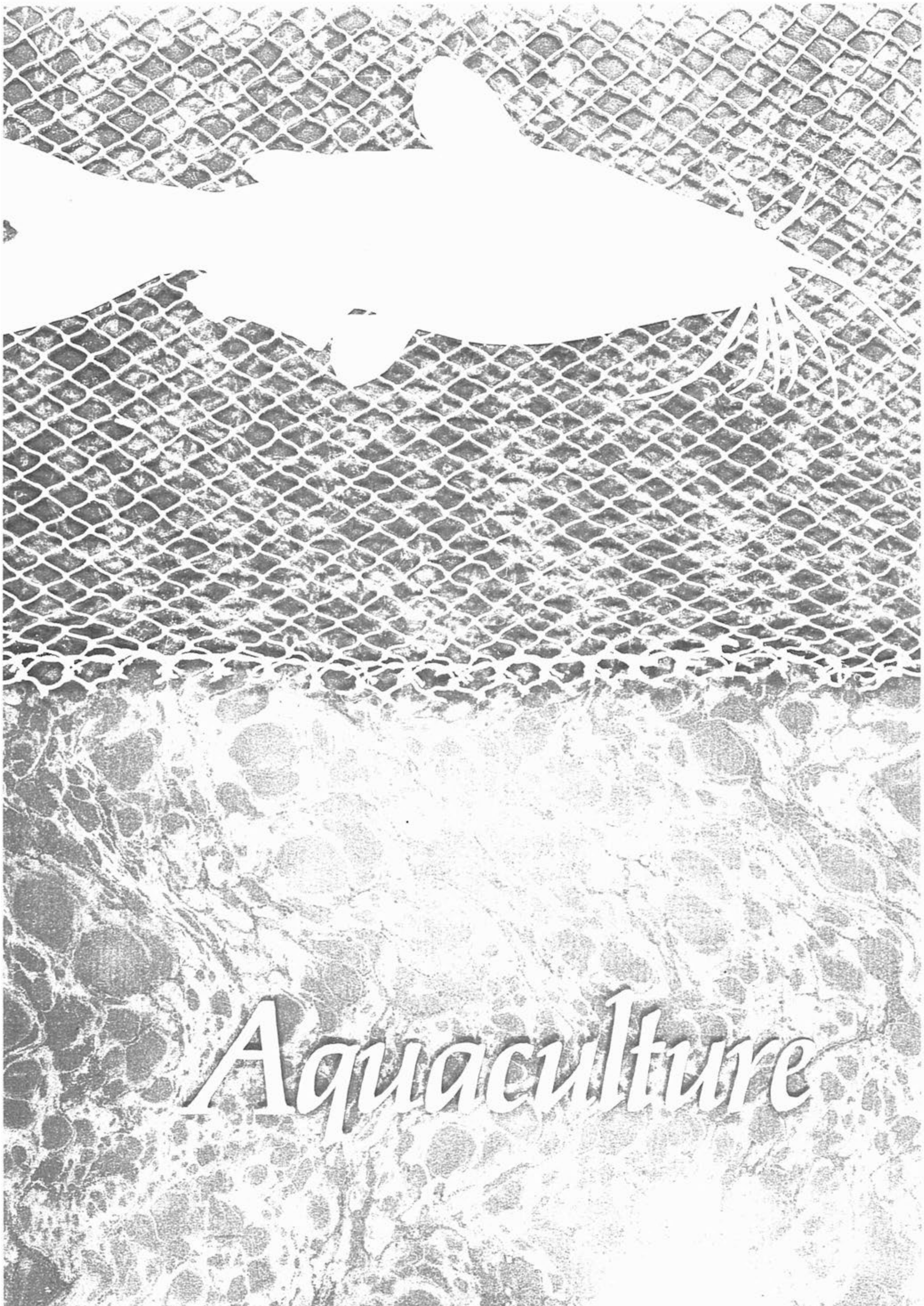
V. PLANT AND ANIMAL SOURCES

J. L. Hudson Seedsman, POB 1058, Redwood City, CA 94064.
Mellingers Nursery, 2310 W. S. Range, North Lima, Ohio 44452.
New York Stage Fruit Testing Cooperative Association, Inc. Geneva, N. Y. 14456.
North American Fruit Explorers
Northern Nut Growers Association, 4518 Holston Hills Road, Knoxville, Tenn. 37914, publish *The Nutshell.*

All my dawns cross the horizon
and rise, from underfoot.
What I stand for
is what I stand on.
—*Wendell Berry*

Photo by Hilde Maingay


Aquaculture

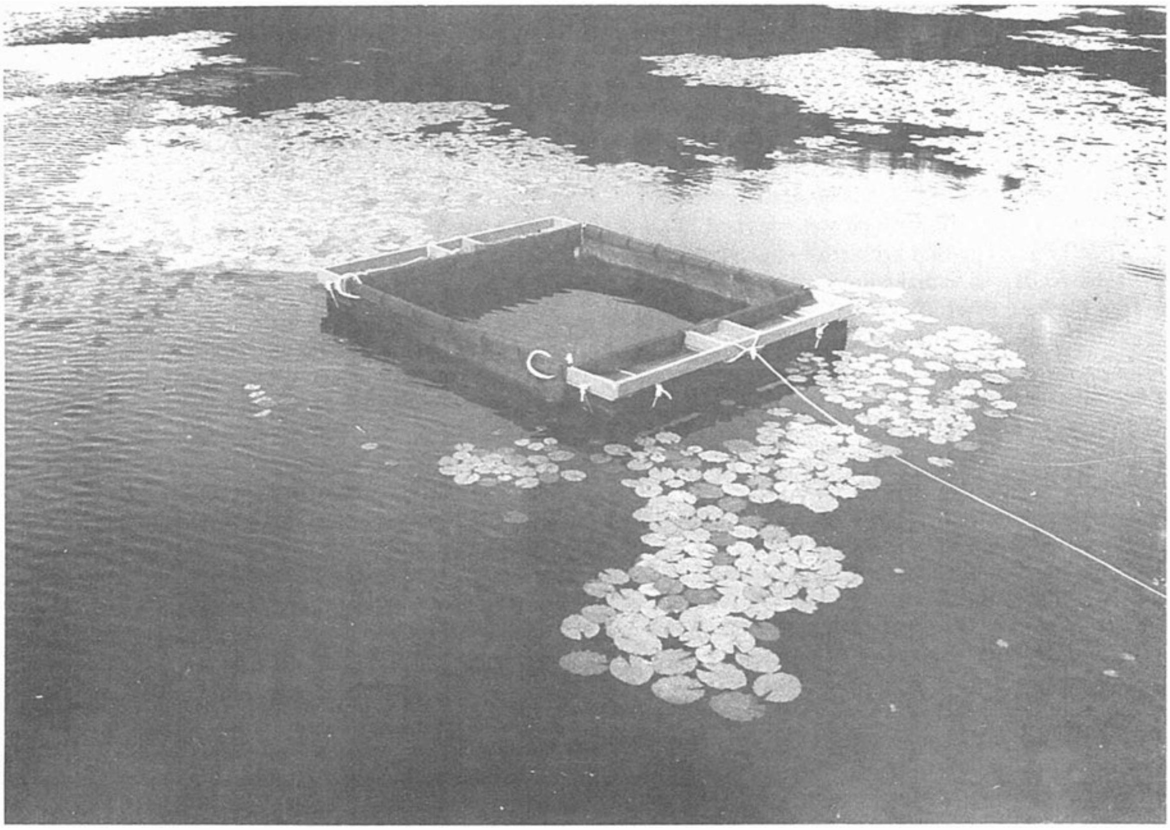
As was the case with our work with the bioshelters, the past year's aquaculture research was marked less by breakthroughs and landmark achievements than the last and more by efforts to understand more thoroughly the systems that we already have. Ron Zweig is in charge of our research in semi-closed system 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 reexamine, 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

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

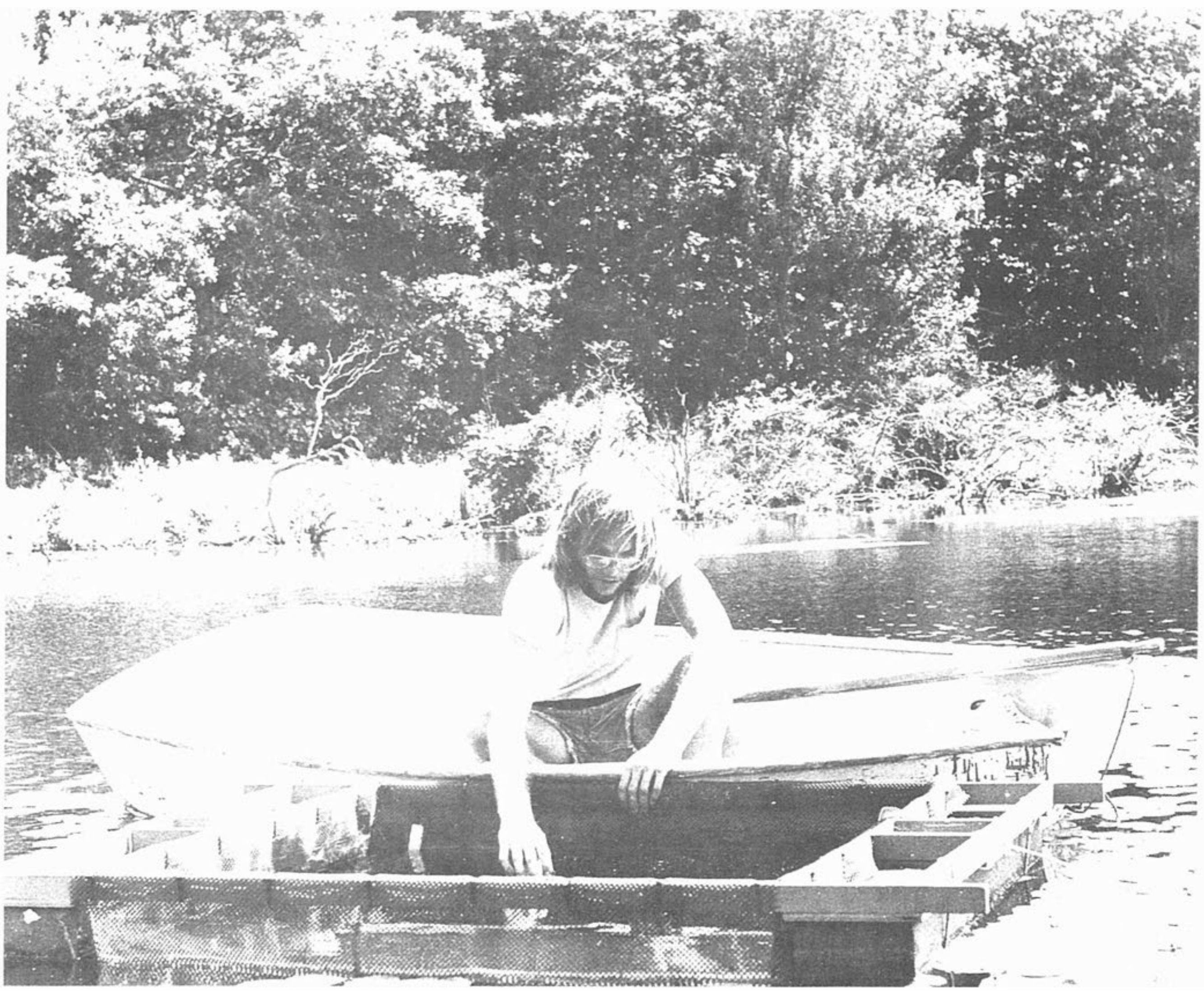


TABLE 3. Growth of young blue tilapia in solar-algae ponds when fed on soy-oat mixture at 2% of body weight/day, supplemented with minced earthworms in amounts equal to 2% or 10% of the soy-oat diet (second of two trials). Data for fish weighing less than 5 grams at the start of the experiment are shown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

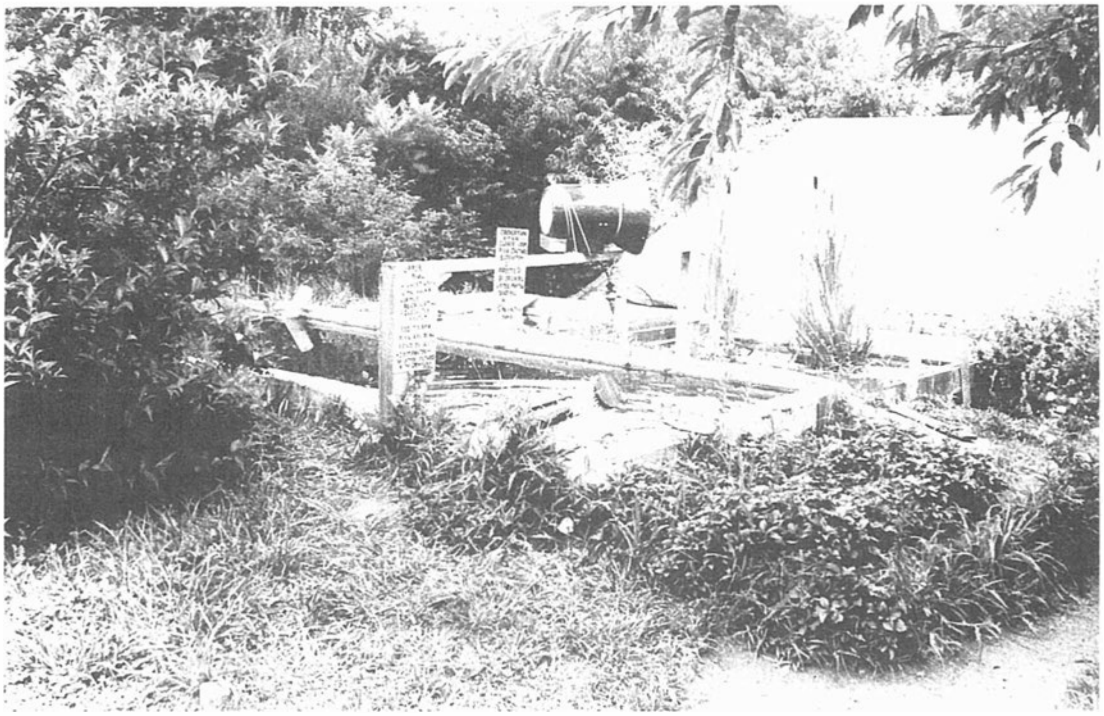
Accordingly, a diet was tested in which approximately 50% of the protein, naturally supplied by fish meal, normally present in commercial trout feed was replaced by fresh minced earthworms and the other half of the diet was supplied by the soy-oat mixture. This was supplemented with midge larvae at the 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

* *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.

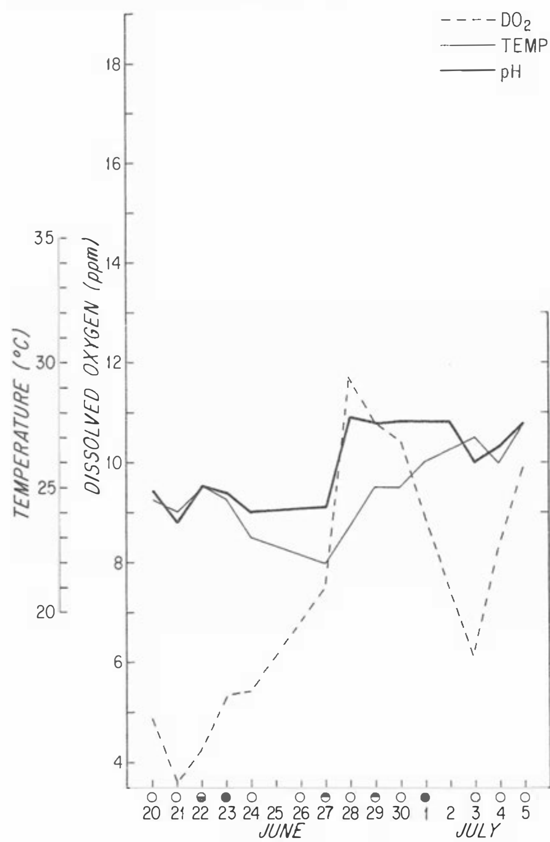
Two weeks after the trial started, a number of the tilapia were weighed. Forty-eight fish from the upper pool weighed 39.8 grams and forty fish from the middle pool 29.2 grams, a weight of 0.8 grams per fish. This was an increase of 0.75 grams per fish or a 16-fold increase after two weeks. The superior 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

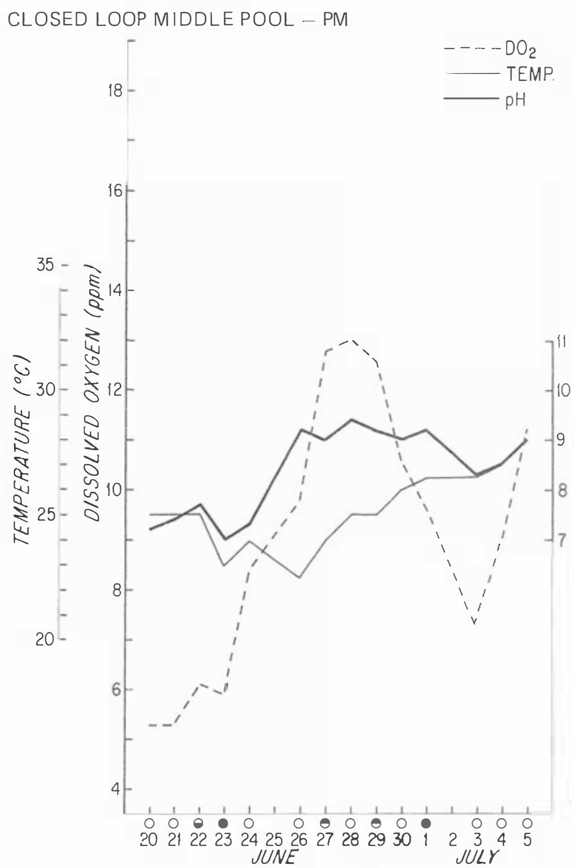
II. The Dome

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.

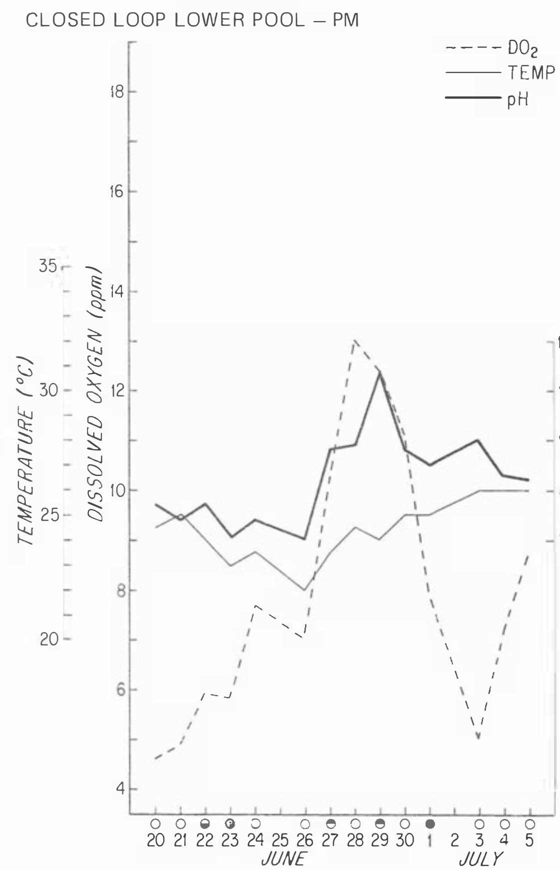
Over three thousand young tilapia were hatched in the system. Commercial food was reduced to one-quarter of that given during the previous summer. Several vegetative feeds were supplied. A quantitative account of this material was recorded. Temperature, DO_2, and pH measurements were taken three times 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."



GRAPH 2



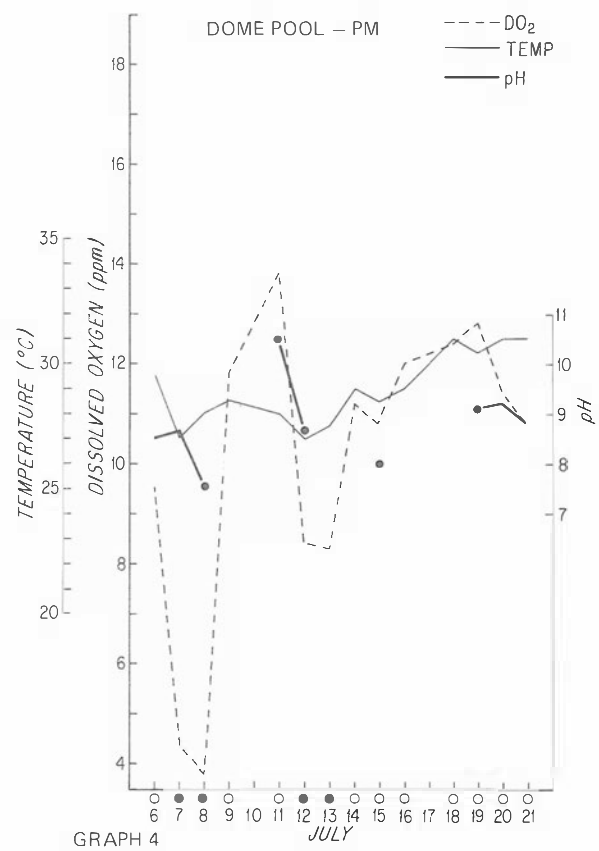
GRAPH 3

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.

* 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.

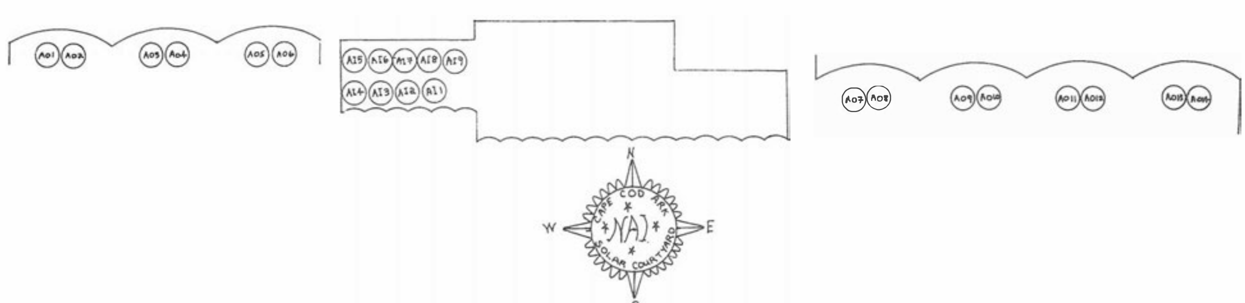


DIAGRAM 1. *This diagram illustrates the location and number of the Solar-Algae ponds in and adjacent to the Ark in the solar Courtyards. The Courtyard reflectors are made of poured concrete and painted white. The ground is covered with highly reflective white marble chips. The numbers of the ponds are indicated in their circled locations. A01 indicates Ark Outside 1, and AI1 represents Ark Inside 1. The diagram is derived from a Solsearch Architecture drawing.*

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 AO*4*'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 Pond Number	Date Fish Introduced	Fish Weight (grams)/Number *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 Tilapia	Mirror Carp	Grass Carp	Total	Conversion ratio (Dry Feed/ Wet Fish)
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
AO9	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 AO*7, 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.

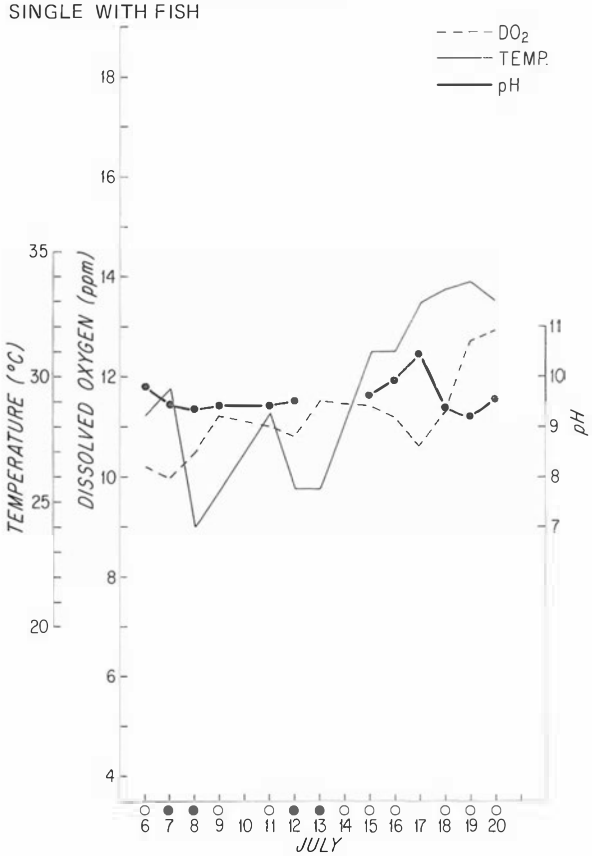
Spotte[14] reports that the higher the pH, the higher concentrations of toxic un-ionized ammonia relative to ionized ammonia. High rates of algal metabolism coinciding with high pH levels may alleviate this by removing ammonia. Ammonia was not detected in any of the ponds in Experiment 5. We are presently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

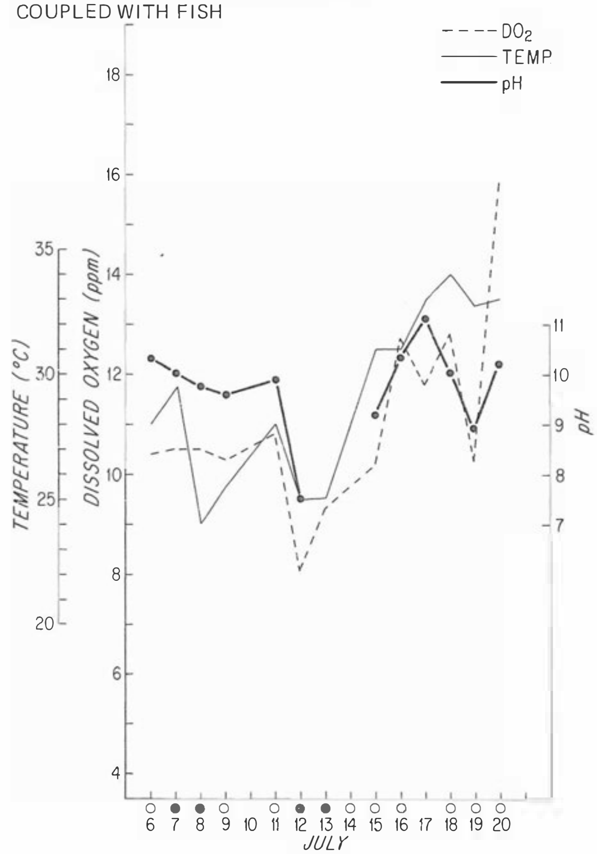
During the middle of November, 1977, the average diurnal temperature fluctuation of these ponds was 12.5°F, a collection and release of about 652,000 BTU. In terms of incident solar radiation, the equivalent time period after the solstice is the beginning of February, close to mid-winter. If the cloud 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



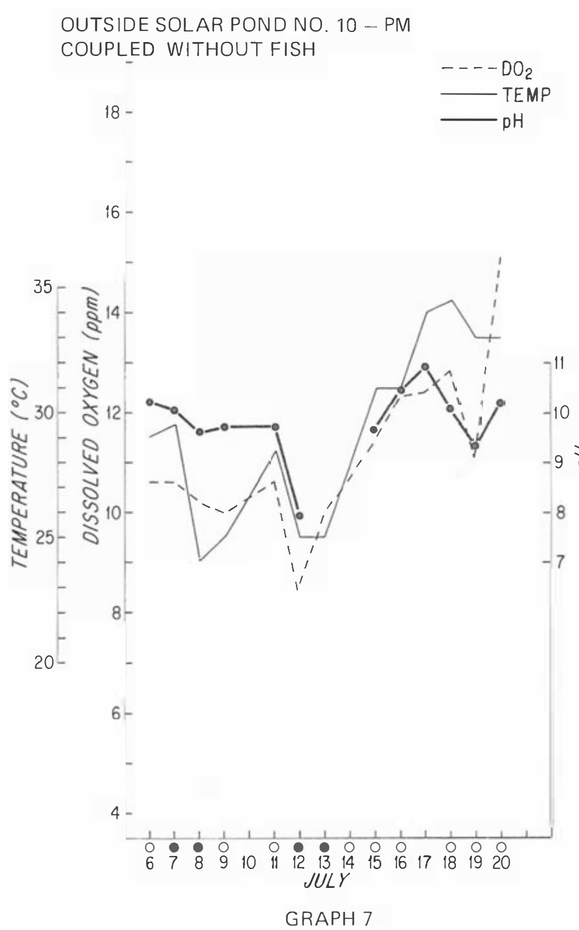
GRAPH 6

Summary of Semi-Closed Aquatic Systems

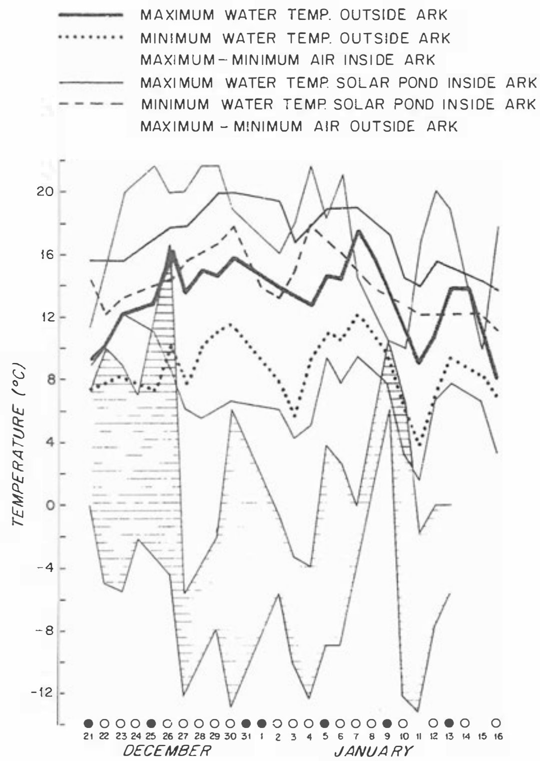
The work described has given us considerable information about the dynamics of semi-closed aquatic systems. Many of the experiments with small quantities of supplementary feeds resulted in low productivity, indicating that food is a major potential limiting factor of such systems. In the intensive feeding 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.



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

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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:

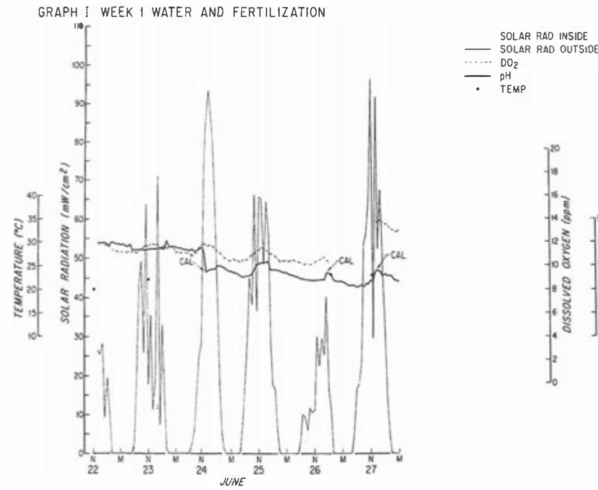
The solar-algae pond in this study is in position AI9 inside the Cape Cod Ark (see Diagram 1)[3], on the upper level of the aquaculture section, beneath the insulated northern roof. A Chemtrix Model 40E pH meter was used to measure the hydrogen ion concentration of the water. A Yellow Springs Instruments Model 57 Dissolved Oxygen Meter was used to measure the dissolved oxygen (DO_2) in parts per million (ppm). Temperatures (^{o}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^{o}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^{o} to 23^{o}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.

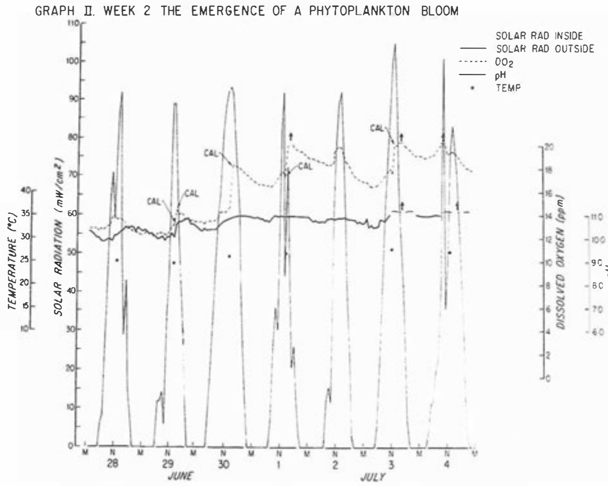


GRAPH I. This figure represents the first week of monitoring Solar-Algae Pond AI9 inside the Cape Cod Ark. Dissolved oxygen is in parts per million and solar radiation in milliwatts/cm.[2] *The pond temperature was measured once daily while the others were measured continuously. The chart recorder ran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

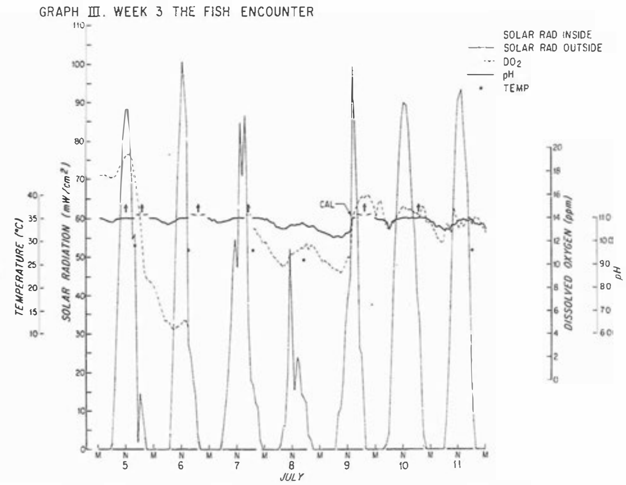
Following fertilization, because of the nutrients being supplied to the phytoplankton, a radical increase in the DO_2 concentrations was measured. The immediate impact of these nutrients cannot be exactly determined, as the DO_2 meter was being recharged when the nutrients were added to the pond, delaying 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 A19. The measured factors are the same as in Graph I.



GRAPH III. This figure represents the second week of monitoring A19.

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]

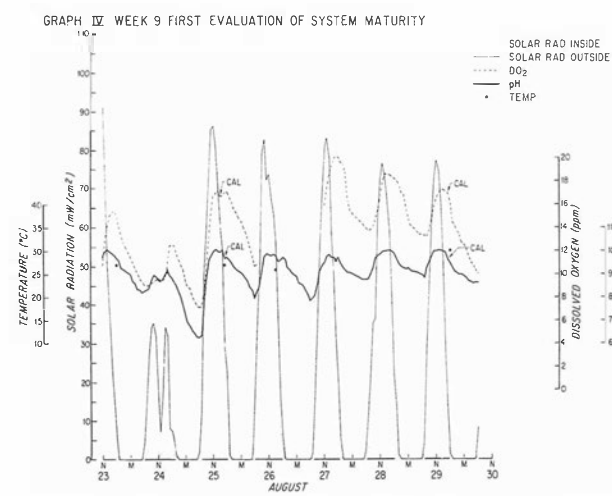
The hourly fluctuations in the DO_2 during the last three days are difficult to explain as other than mechanical error. The pH levels during these days, particularly the last two days, show a steady decrease. The small amount of organic matter that was building up in the pond would have tended to drive 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 A19.

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.

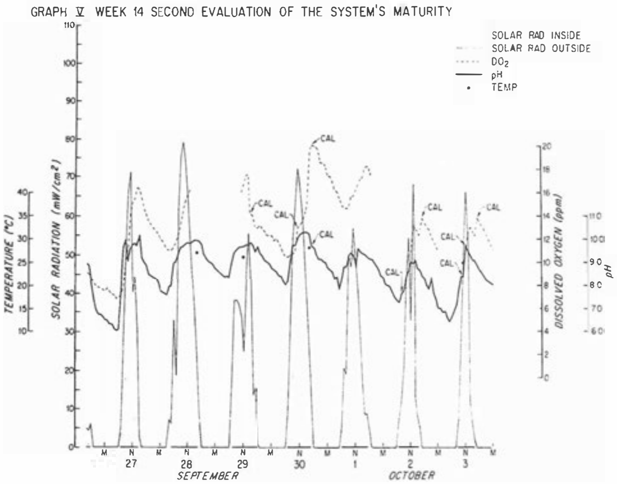
Week 14. Second Evaluation of the System's Maturity:

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.

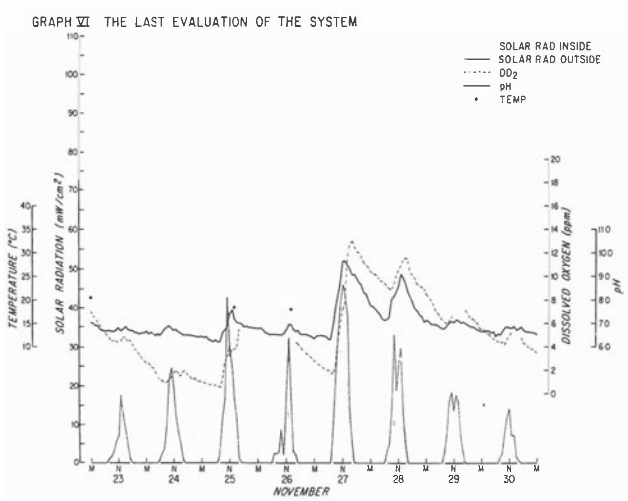
ecosystem. The combination of low light level and a build up of detritus on the bottom reduced diurnal curves. Compared to previous graphs, the fluctuations of November 27 and 28 are less, but sufficient energy to drive the system is still available. The lower oxygen levels are still well within safe 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.

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.



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

* * * * * * * * * * *

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.

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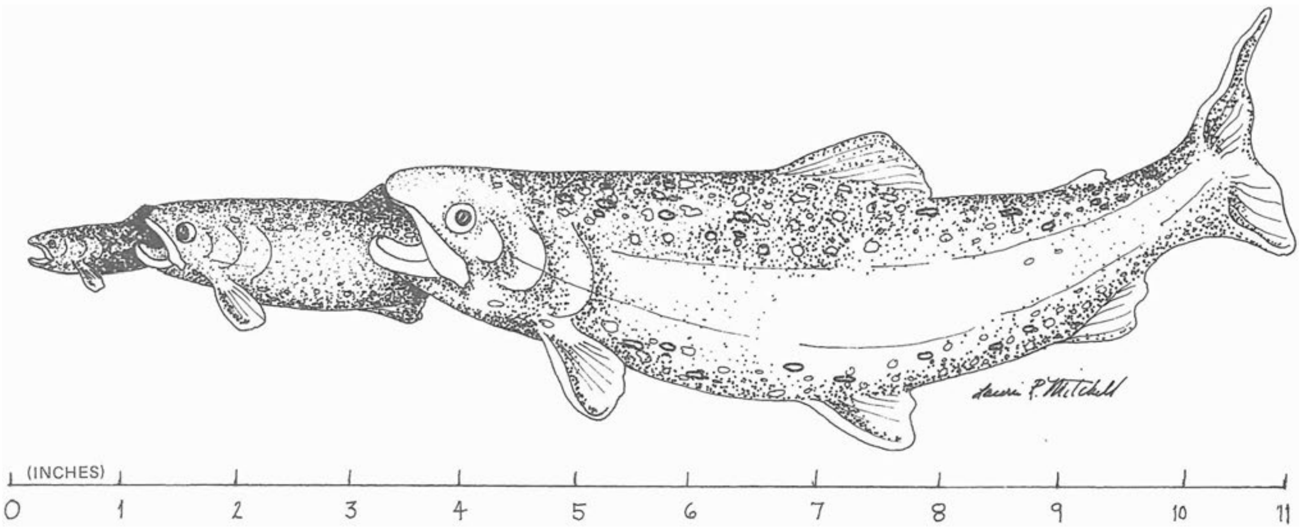

The Second Wave:
The Application of New Alchemy Aquaculture Techniques to a Remote, Small-scale Trout Farm

– 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.

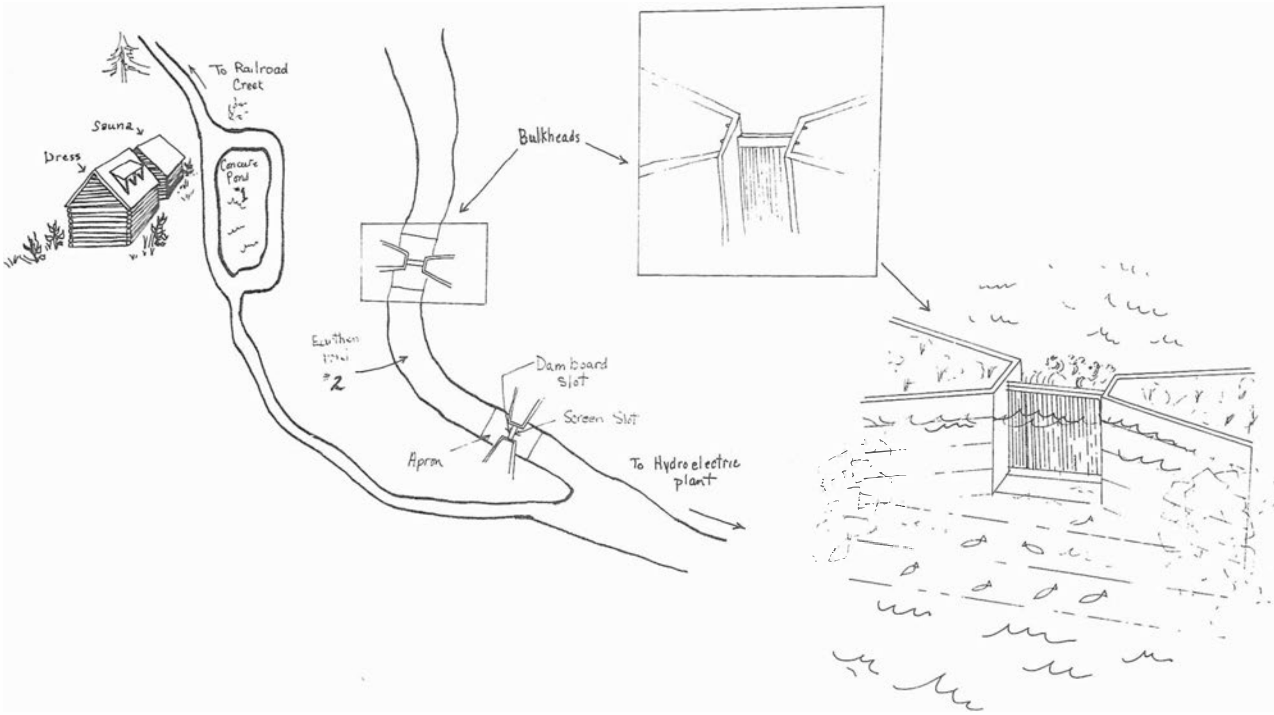

Fig. 1

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

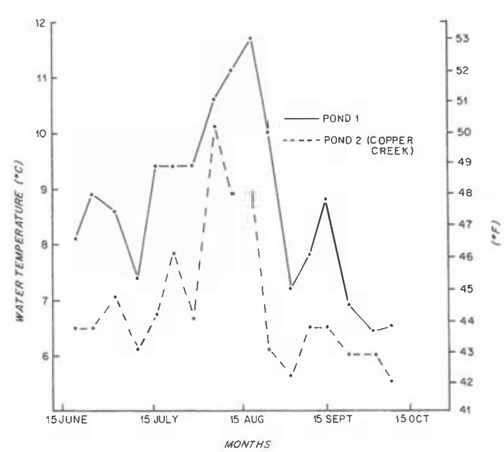

Fig. 2

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%

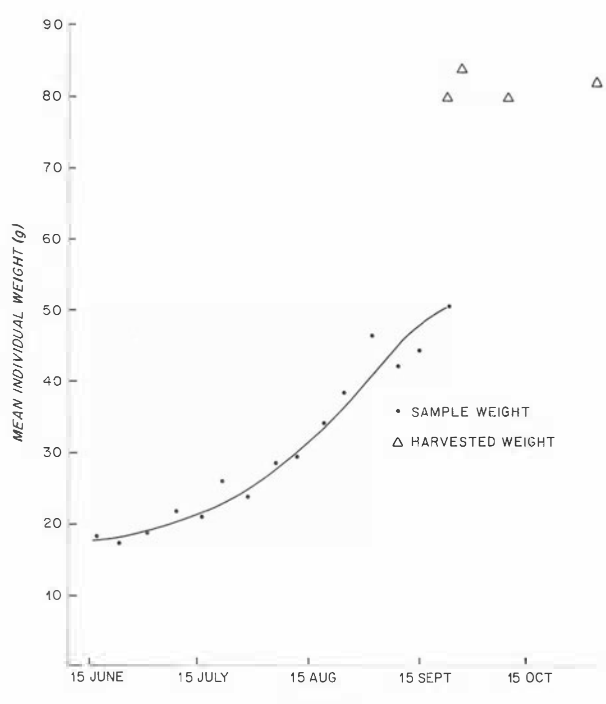

Fig. 3

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.

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Photo by Hilde Maingay

Brochures

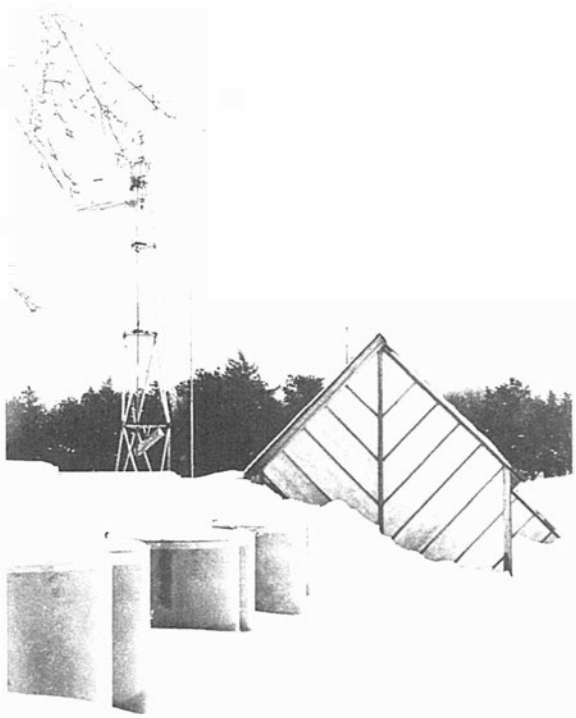

Photo by Hilde Maingay

Our most recent bioshelters, the Arks on Cape Cod and Prince Edward Island, have been in operation for just over a year and a half, as of this writing. They have come through two long, cold winters with flying colors and little or no fossil fuels. As was explained earlier, the P. E. I. Ark is now managed by I. M. R., a local Island organization.

Unquestionably, both buildings will take years of study before all the questions posed by the concept of the bioshelter can be answered adequately. Areas to be explored are: biological, in terms of suitable horticulture and pest management; ecological, in the finding and filling of sufficient niches to establish interior homeostatic balance; energetic, in studying the efficiency of the absorption and retention of solar heat; aquacultural, in that fish production is a significant potential source for protein and that, in our structures, the aquaculture is an inseparable climatic component of the overall unit; economic, with regard to the possibilities for income from a local market for the produce of such a structure, and, finally, cybernetic, as we monitor and try to understand some of the less discernible gaseous, chemical and biological exchanges that qualify this type of building, more than others, as a living structure. Several of these fronts are covered in the articles in this section of this issue.

Kathi Ryan, whose gift for plants brings the Ark to life, describes her work in "Soundings from the Cape Cod Ark." In "Biotechnic Strategies in Bioshelters", Earle Barnhart discusses more generally the methodology and potential for solar greenhouses. And in "Where Does All the Heat Go?", Joe Seale explains how to create a computer thermal model for a solar greenhouse and what it means. He recounts working out the model for heat flow in the P. E. I. Ark and explains the usefulness of such modelling in the conceptual advancement of solar architecture.

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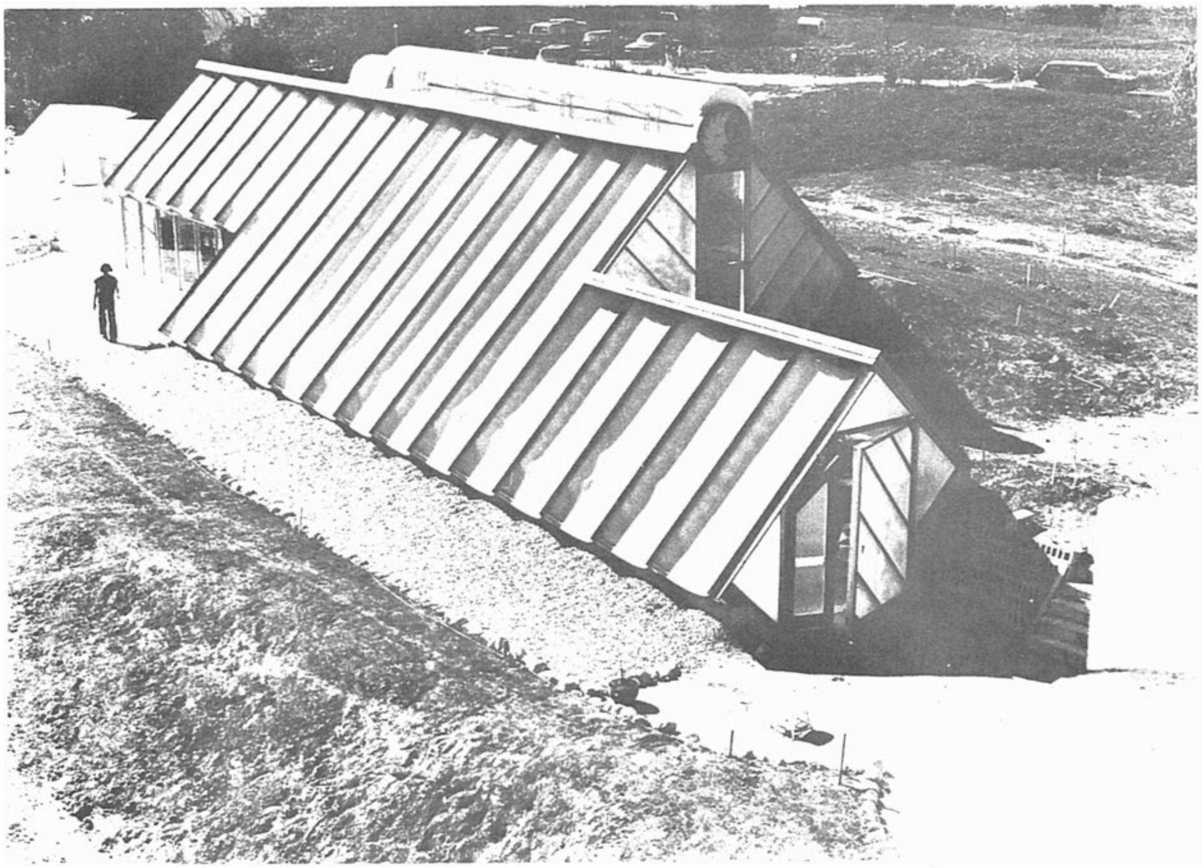


Biotechnic Strategies in Bioshelters

-- *Earle Barnhart*

ELEGANT ENTROPY

From the recent expansion of solar-oriented architecture, design principles are emerging similar to the biological strategies found in natural living systems. The components of living systems have mechanisms of collection and storage to cope with fluctuations of energy supply. Plants generally absorb sunlight and store energy chemically as sugars, starches or other materials in their structure. Many animals ingest food energy periodically but use it gradually. Warm-blooded animals have the additional strategy of conserving heat for their energy use with fur, feathers or other forms of insulation. Whole communities of organisms living in cold regions have evolved heat-conserving surface area-to-volume ratios, and many species develop special night-time and winter behavior such as hibernation. Where plant and animal strategies co-evolve over time at the level of the ecosystem, a structure is developed which reduces the effects of extreme fluctuations of temperature, humidity, wind and other environmental parameters. An important result of such an interacting community is a mutual reduction of physiological stress on its members.

In a mature ecosystem, trees, shrubs, grasses and other plant structures affect climate mainly by reducing wind velocity and restricting radiant heat loss. In a forest or meadow, wind reduction results in stabilization of air temperature, evaporation and soil moisture. A gaseous membrane of air, water vapor and carbon dioxide near the ground affects incoming and escaping radiation. The quantity of energy involved in evaporation and condensation is a significant factor in daytime cooling and night-time heat release. These combined environmental buffering effects create relatively stable microclimates and new habitats

Photo by Hilde Maingay

for organisms within the ecosystem. As the ecosystem grows more diverse, it becomes more efficient at capturing available sunlight, produces more food and can support still more organisms.

Generally then, a terrestrial ecosystem partially buffers environmental extremes and diversifies gradually to become more efficient at capturing diurnal and seasonal pulses of sunlight. The solar energy captured as both heat and food is conserved and subsequently slowly expended in biological activity before being lost to the sky as thermal radiation.

ARCHITECTURE AND BIOTECTURE

"Ultimately the natural and technological solutions will be indistinguishable."

— *Jono Miller*

Solar greenhouses, as well as more complex bioshelters, are architectural forms designed to protect and nurture plants, animals and people. Successful solar greenhouses should incorporate many of the principles found in successful ecosystems and a greenhouse architect should realize that biological systems are a potential source of strategies useful to solar design. Solar greenhouses must combine the energy-collection function of a plant, the heat-conserving process of a warm-blooded animal and the micro-climate formation of an ecosystem. The architect must integrate effective solar orientation and thermal storage so that the food crops selected have optimal ranges of temperature, light and moisture.

Much traditional building design and even some solar greenhouse design confine the analysis of the energy dynamics of a structure to its outer "shell", calculating energy inputs of sunlight and radiant heat and losses of reflection, radiant heat and infiltration. The more subtle dynamics of the ways in which input energy is absorbed passively, stored and channeled within the structure are only beginning to be investigated and understood. We know that the best passive solar buildings can coordinate light, thermal mass and convection and create a zone of very stable temperature. This type of sophistication is important in designing spaces where several different species are to interact yet each species has specific environmental requirements. The design of a bioshelter must reflect these needs. Ideally, the architectural design of a successful solar greenhouse and the ecological design for successful horticulture will be integrated, architectural forms merging with ecological function. Our Cape Cod Ark attempts such a fusion.

In a household greenhouse, food crops are the major components of the ecosystem. An internal light and temperature regime suitable for a mixture of fruits and vegetables is the primary goal of the architect. To cope with immigrating pest species, successful ecological management of an outdoor garden suggests that an alternative to persistent biocides is a permanent population of predators within the structure. It is not yet known how few species or organisms can comprise a human-dominated, permanent food-producing, self-regulating garden ecosystem without pesticides. One possibility is to duplicate as nearly as possible the ecological patterns of a successful outdoor garden. Each of the plants, pests and predators requires a slightly different range of temperature, light, moisture and habitat. The challenge to the greenhouse designer is to create many microclimates in order to foster highly diverse forms of life.

DESIGN PRINCIPLES

"In wilderness is the preservation of the world."

— *Henry Thoreau*

Concepts of ecological architecture and ecological engineering are beginning to be intensively investigated with relation to agricultural systems. Principles of design potentially useful to the architect are strategies that encourage greenhouse systems to become self-adapting. The following are general rules for biological design in solar greenhouses.

I. *Architectural forms should create microclimates that nurture a diversity of different plants and animals.*

A microclimate should be created which includes zones for major crop plants, minor crop plants including herbs and flowers, maintenance organisms such as predatory, parasitic and pollinating animals, soil organisms for decomposition and recycling and, if possible, aquatic communities which interact with the terrestrial community. Microclimates are created by intentionally shaping the solar greenhouse and its interior structure to result in variations in sunlight intensity, air temperature, soil types, moisture conditions and types of habitat surfaces. Specific structures that can be used include terrace levels, raised or lowered beds, stone walls, passive thermal walls, vertical arbors and tiny ponds.

II. *Every available ecological niche and habitat should be filled with selected organisms.*

a. *Soil and soil organisms* from a normal garden should be added to the crop-growing area. This soil will introduce bacteria and microorganisms adapted to the culture of vegetables as well as common surface animals such as crickets, spiders and beetles. Other types of soil from fields, meadows and forest floor should be included. Compost and earthworms should be distributed in all beds. The goal is to assemble many types of soil organisms which may adapt to the different microclimates.

b. *Major and minor food crops* will occupy much of the growing area. Food crops may be changed with the seasons. Many plants have an optimal season of production based on day length while others are affected by temperature. Test plots and close observation will indicate which food plants are productive in a particular area throughout the seasons. Mixed species of food plants offer a more interesting and sustainable human diet and gradually provide insect habitats and food sources for both pest and predators.

c. *Permanent ecological islands* to harbor populations of regulatory organisms can be created. The predators, parasites and pollinators which help in sustaining agriculture need special soil and plant associations. Predators include toads, frogs, chameleons, spiders, beetles, damsel flies and other insects. Microscopic trichogama wasps are useful parasites and wasps, flies and bees are pollinators. Ecological islands are protected zones undisturbed by seasonal harvests, the removal of crops or soil cultivation. Such permanent zones encourage cumulative diversification in the ecosystem by harboring accidental colonizers from the outside. Permanent populations of many organisms of many species may be essential for ecological succession and for self-regulation within the bioshelter. Attempts should be made to preserve a wide range of natural diversity because we cannot always know which species are necessary for long-term function. Ecological islands can take such forms as permanent herb plots, an area of meadow sod or forest litter, a rotting log, a rough stone wall, a tiny pond or a permanent tree or vine.

III. Adaptation and succession should be encouraged.

A solar greenhouse environment, however well designed, differs from the outdoor environment in such respects as altered light quality, higher humidity levels and lack of bird predation. Over several years, populations of soil microorganisms, insects, and even larger predators will adapt to a new environment. Pests and predators will become established, find ecological niches and develop new relationships. The process engenders the gradual development of new food chains based on new associations of crops, pests, predators, parasites, pollinators and decomposers. A designer can facilitate succession in several ways. One is by providing for maximum interaction and travel among microclimates. Soil connections between growing beds permit earthworms, soil organisms and surface animals to move freely. Small ponds at soil level give animals access to moisture. Ecological islands in corners and near crop areas provide convenient shelter for predators. A second method for encouraging adaptation is periodic reintroduction of outdoor soil, insects and potential predators. As permanent plants become established, new habitats develop. Two-way migration between the outdoors and the greenhouse in the warm season is a third successional strategy.

Another possibility for general adaptation occurs when an aquaculture pond is used to recycle weeds or plant wastes by feeding them to fish and, in turn, is a source of fertile irrigation water for the crops. The aquatic nutrient loop can eliminate plant diseases which could be carried over in plant wastes. Bacterial and biochemical changes utilizing exchanged nutrients in both aquatic and terrestrial systems take place.

IV. Gaseous exchange must be stimulated.

Air movement by winds and local convection plays an important role in the exchange of water vapor, oxygen and carbon dioxide across leaf surfaces. This air movement speeds evaporative cooling, provides carbon dioxide for photosynthesis and removes waste oxygen. In nature, considerable carbon dioxide comes from the decomposition of organic matter caused by respiring soil organisms. Whereas a greenhouse using sterile soil can become depleted of carbon dioxide without an outside supply, a greenhouse with fertile soil containing organic matter and microbes has a slow-releasing reservoir of carbon dioxide. Nutrients removed from the system as food must be periodically resupplied by adding compost.

V. Cumulative toxins and biocides must be avoided.

Some of the pesticides used in agriculture are indiscriminately lethal to multitudes of organisms. Even Rotenone, considered relatively mild, is toxic to many cold-blooded animals such as toads and fish. Pesticides, herbicides, fungicides, wood preservatives and some paints contribute toxins or heavy metal compounds which are passed through food chains and accumulate in top predators including humans. Organic matter such as grass clippings, sewage sludge or food wastes should be evaluated as possible sources of biocides.

RESEARCH AND DEVELOPMENT AT THE NEW ALCHEMY INSTITUTE

Following is a list of bioshelter sub-elements that we have investigated at New Alchemy to date:

a. *Solar-algae ponds* or semi-closed aquatic ecosystems for fish protein production. Solar-algae ponds provide food, indoor nutrient cycling of greenhouse plant wastes and enriched irrigation water. Equally importantly, they serve as passive solar collectors and thermal storage mass for climate moderation.

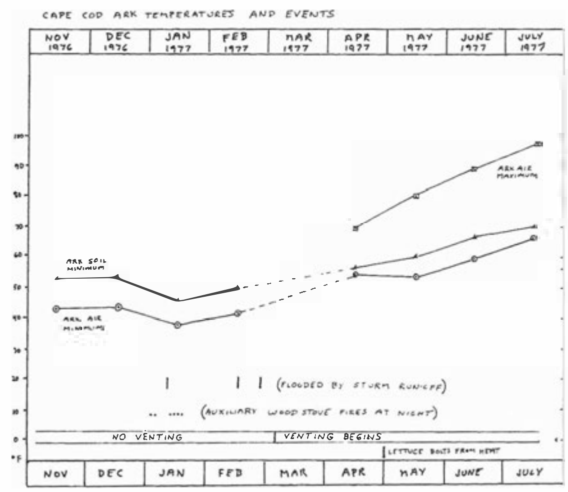
b. *Agricultural ecosystems* of vegetables, herbs, seedlings, tree cuttings, ornamentals, dwarf fruit trees and associated pests and predators.

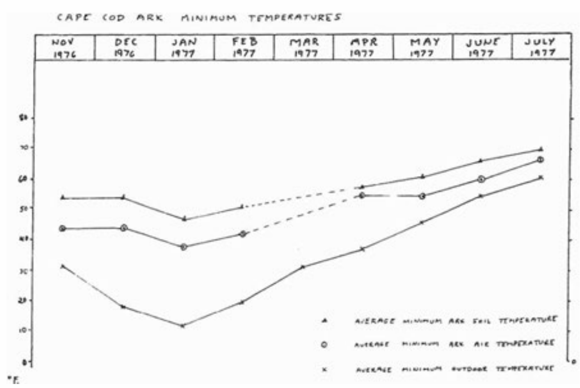
c. *Integral human habitation* for operators of bioshelters, where people live within the structure, exchanging heat, food and waste materials with the greenhouse environment, as in the case of the Ark on Prince Edward Island.

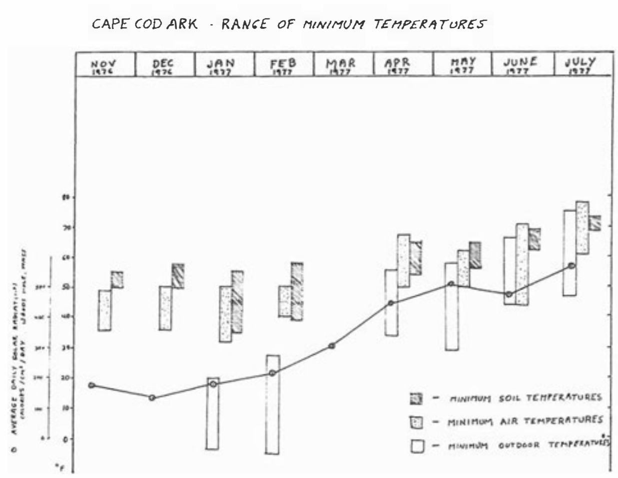
d. *External components* including reflective solar courtyards for sunlight concentration, rainwater collection from the rooftop as a supplemental water supply and living plants for winter windbreaks and summer shading.

Bioshelter concepts yet to be developed include:

a. *Agricultural hydroponics on solar-algae ponds* utilizing a potential niche which is stable and has a constant water and nutrient supply.







b. *Human waste and water recycling* which are biological processes and should return nutrients to a locally productive use. Throughout the world aquatic ecosystems are used for rapid cycling of many organic waste materials. In Canada, the Prince Edward Island Ark has a Clivus Multrum for solid human wastes. Treated grey water is being tested for irrigation in California. Conceivably, a linked aquaculture/hydroponics/irrigation system could recycle human wastes locally.

c. *Selection of crops* specially adapted for solar greenhouse conditions.

d. *Water distillation* from condensation on glazing. A significant fraction of solar energy absorbed by a plant evaporates water. On cool nights as energy is lost from a solar greenhouse, vapor condenses on the inner glazing surface producing a small supply of fresh water.

e. *Seasonal multi-use of greenhouse structures:*

i. Winter vegetable production and sale.
ii. Winter supplemental home heating.
iii. Spring seedlings for outdoor agriculture.
iv. Summer solar drying of surplus garden food.
v. Domestic hot water pre-heating.
vi. Water distillation.
vii. Tree propagation.

EPILOGUE

The principles described above are examples of workable ecological design concepts in which architecture is one of many factors. The sun, soil, plants, animals and water are equally important. In the microcosm of a solar greenhouse everything is connected perceptibly to everything else: the architecture to the sun and the plants, the plants to the season and the soil, the soil to the people and their habits and people's habits and their needs to the region. At New Alchemy we are contemplating these relationships in the hope that, with a better understanding of the workings of nature, we may gain greater respect for our place in it.

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Soundings from the Cape Cod Ark

— Kathi Ryan

The solar greenhouses at New Alchemy are designed to grow a variety of food plants Their internal environment is a modification of outdoor temperature and light cycles. The growing areas include several microclimates so that many different vegetables can be grown simultaneously in slightly varying habitats.

Plants growing in a greenhouse are affected by several conditions different to those in the normal outdoor garden. These include altered light quality, reduced wind, greater relative humidity and absence of normal pests and predators. Vegetables which have been selected and bred to do well outdoors are affected by this variance in conditions. Some of the detrimental effects can be minimized by careful design. Others may require the development of special strains of vegetables for solar greenhouse use.

Light quality inside a greenhouse is affected by the type and thickness of glazing. Various types of materials have been shown to exclude infrared, ultraviolet or other wavelengths of normal radiation. Several layers of glazing can reduce significantly the intensity of sunlight entering the building. The length of day perceived by a plant is altered if the morning and evening light is excluded by solid walls. Such effects limit the range of plants which can be grown.

Reduced wind has several subtle effects. Air movement across the surface of leaves helps in the exchange of gases during photosynthesis and respiration.

Gentle movement from the wind encourages some plants to develop a morphology that is sturdier and more compact than they would in still air. Condensed morning dew, which can encourage fungus growth, is evaporated quickly by air movement. Some plants require wind for successful pollination.

The range of influences of high humidity is unclear. Plants have been known to grow normally in very high humidity, yet still need easy transpiration for daytime cooling. Relative humidity in our greenhouses is often one hundred per cent from evening until morning, but during sunny days drops to forty to sixty per cent.

The effect of air temperature on plants is complex and varies with species. With greenhouse temperatures, careful distinction should be made of the point at which the measurement is taken. The air temperature experienced by someone in the greenhouse may be very different from that existing simultaneously near the ground among the plants. Soil temperature and upward heat radiation affects plant growth in ways not discernible from wall temperature measurements. Most plants have optimal growth conditions but can tolerate a range of temperature without damage.

We have observed that some vegetable production, such as lettuce, can be limited by high temperatures and others, like eggplant, by low temperatures. A microclimate averaging a few degrees higher than its environs can induce higher production in warmth-loving plants such as peppers or green beans. Similarly, cold drafts can suppress growth. We are experimenting and gradually discovering which are the best light and heat zones for various vegetables within the greenhouse.

Insect pests outside have many natural predators, such as birds, toads and other insects. Most of these predators are absent in a greenhouse and pests can spread rapidly. Frosts and frozen ground, which prevent pests from maintaining constant active populations outside, are not useful deterrents inside. Biological pest control simulating garden processes is the most promising alternative to the use of pesticides in a greenhouse.

Construction on the Cape Cod Ark was completed in the fall of 1976. Our first winter's crops were primarily transplants from the summer gardens. Warm, fertile fish-pond water from the aquaculture projects inside the Ark was used for irrigation.

The first winter we grew lettuce, kale, swiss chard, spinach, parsley, endive, onion tops, beet greens, turnip greens and an assortment of herbs. Most of these plants underwent a slower period of growth from mid-December to mid-January but continued to produce throughout the winter. The lull was primarily due to the low angle of incoming sunlight and the short daily light cycle. Less hardy plants, such as tomatoes and peppers, did not fare too well.

Despite the severity of the 1976-1977 New England winter, the plants in the Ark did not freeze at any time. Temperatures dropped to near freezing one night in early February. During a week of continuous, heavy rains, a gale force wind blew one of the vents off the roof. At that time, the drainage system was as yet incomplete and, as the ground was frozen hard, the building was flooded. During that week we used a wood stove for auxiliary heat. Toward the end of February, as the days grew longer, temperatures in the Ark began to rise noticeably. Even on partially cloudy days, noon temperatures were in the high seventies and eighties and venting was necessary. Moments after the doors and vents were opened, honeybees, attracted by the scent of nasturtiums and herbs in flower, would swarm in.

During the first winter, pest problems were limited to slugs and a few whiteflies. The whiteflies stayed in the nasturtiums during the colder months and were relatively harmless. In mid-April, when the minimum temperatures averaged fifty-five degrees, whitefly activity increased. Aphids and cutworms appeared in the early spring but generally caused less damage than the whiteflies. The cutworms were mainly controlled by handpicking although marigolds acted as trap plants. Handpicking five hundred cutworms for an hour a day was somewhat arduous but proved effective.

Aphids were controlled by the many predators that cohabit the Ark. Spiders were the most effective predator. Each morning webs containing up to one hundred whiteflies could be found. We introduced lacewings as predators. Other predatory insects included damsel flies, praying mantises and a variety of insect colonizers. Chameleons, toads and snakes were introduced and proved effective components of pest management.

The whitefly is common to commercial greenhouses due to constant relatively high temperatures. Whitefly populations flourish between fifty-eight and sixty-five degrees F. In addition to sucking plant juices, the whitefly secretes a sticky honeydew substance on which grows a mold. Black Sooty Mold prevents photosynthesis. Most commercial greenhouses use large amounts of poisons in attempting to eliminate the whitefly. The whitefly persists, however, by hybridization and adaptation to pesticides. We look to integrated biological controls as the most promising long-term solution.

In early July, parasitic wasps (*Encarsia formosa*) were introduced into the Ark as a control for the whiteflies. This tiny tropical wasp parasitizes by ovipositing an egg inside the third larval stage of the whitefly. Within four days the larval scale turns black. With optimum climatic conditions, an adult wasp will emerge from the black scale approximately twenty-eight days after parasitization. By the end of July we observed fifty per cent parasitization. The *Encarsia* had eliminated the whiteflies by early September.

Further experimentation and understanding of pests and careful timing in initiating controls are integral to productive ecological greenhouse balance. The grower needs to identify common pests and to study their life and reproductive cycles, their food and habitat preferences. With careful monitoring and integrated pest management, the need for pesticides can be reduced or eliminated.

Although biological controls and integrated pest management were the major focus of the summer research, a variety of crops was planted for observation. Due to frequent venting in the spring, it was late May before the soil temperatures were warm enough for melons, peppers, okra or tomatoes.

Most of the plants grown in the Ark in the summer produced an abundance of foliage but less than normal fruit. Even with maximum venting, the building occasionally reached temperatures of one hundred degrees F. and higher on windless, sunny days.

The tropical fruit trees did well in the hot, humid environment. They were relatively unaffected by pests and grew rapidly. Malabar spinach, a tropical vegetable, gave tremendous yields from mid-summer to the beginning of October. It climbed trellises and poles, producing large amounts of excellent spinach all the while.

This winter we are again experimenting with varietal lettuce testing. Five varieties of greenhouse lettuce are being grown and compared to five varieties of outdoor lettuce. We are measuring food production per square foot and monitoring the effects of different organic fertilizers and different light levels. We are using reflectors to determine the importance of light on plant growth and are heating soils and comparing plant growth rates with unheated soils. Maximum space utilization and microclimatic variations are also being studied.

Photo by Hilde Maingay

Over a longer time, we plan to take advantage of high temperatures during the growing season for tropical fruit production and for the mist propagation of trees. Reforestation and the establishment of agricultural forests are a high priority at New Alchemy. In the spring we shall be using the Ark as a nursery for the seedlings and cuttings.

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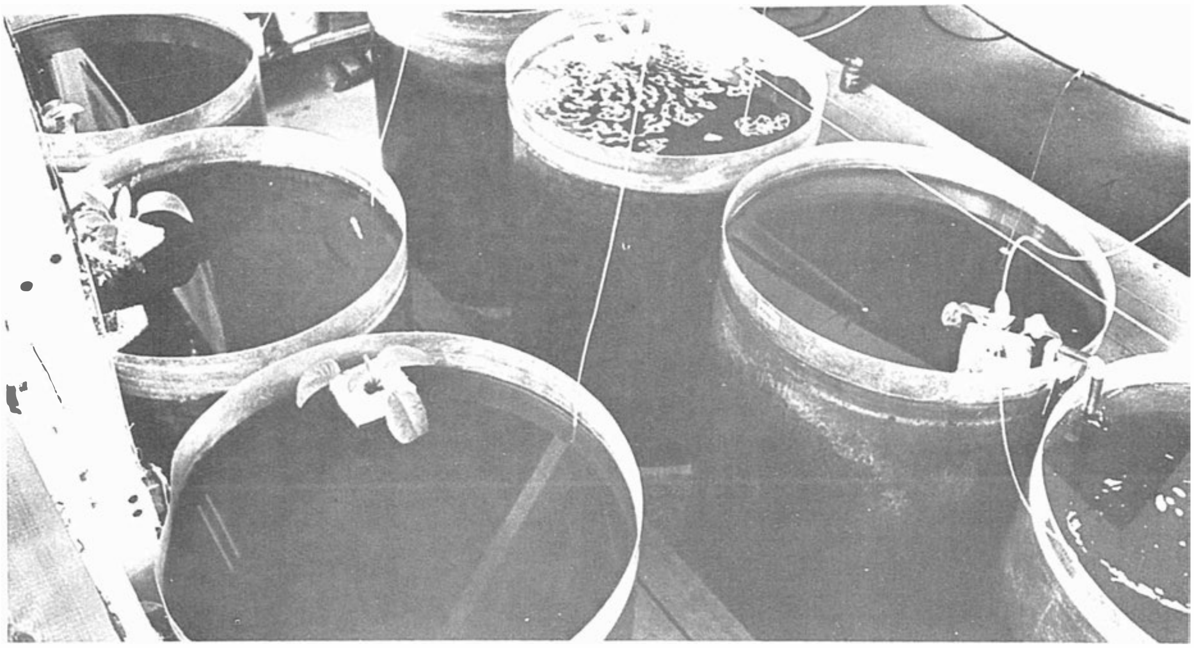


Where Does All the Heat Go?

— Joe Seale

In collaboration with Solsearch Architects, the New Alchemy Institute has built two Arks, one on Cape Cod and one in Maritime Canada. The Ark on Prince Edward Island to be described here differs from the Ark on Cape Cod in that it is a human habitation as well as a micro-farm. It has, as well, its own power-generating and waste treatment facilities. In the Prince Edward Island Ark, bioshelter design combines the various support elements into a single structure.

Efforts to apply ecological strategies in the design of the Ark have led to a number of bio-technical break-throughs. An example of the benefits of a structural shift to a new design paradigm is that the Ark is not only a house. It is among other things a fish farm. The fish culture system is not only for rearing thousands of fish for market but also provides some of the Ark's climatic needs.

The aquaculture facility was designed as both a low temperature (30-35° Centigrade) solar power heat collector and a fish culture complex. There are two rows of 40 solar-algae ponds within the Ark. Light enters the building through the translucent south roof and wall exposing the ponds to solar radiation. The aquaculture ponds have highly translucent walls and contain dense blooms of light-energy absorbing algae. The algae not only provide feed-stock for the fish but act as efficient solar collector surfaces. The water-filled ponds perform as heat storage units. Unprecedented levels of biological productivity have been reached in the solar algae ponds. Fish production per unit volume of water is the highest recorded for a standing water body. This is not the sole function of the aquaculture facility. When temperatures drop in the large greenhouse area and in adjacent rooms including the laboratory, heat is radiated from the ponds and the building is warmed.

The design of the solar-heated aquaculture facility was the result of our deliberate search for processes in nature which, when combined with appropriate technologies, would substitute for fuel-consuming, capital-intensive hardware. In this case, living organisms and a renewable form of energy were asked to replace some of the functions of machines. For example, light was substituted for a range of energy-consuming and expensive equipment normally used for biological regeneration and circulation in the aquaculture ponds. The ponds are made with walls that allow over 90 percent* of the light to enter through the sides. Their placement in the structure where they can best receive solar energy, and the introduction of microscopic algae which absorb the incoming energy, purify the water of fish toxins and provide feedstocks for fish result in a new and ecological approach to fish culture and climate regulation. The bulk of machinery, energy demands and external fish feeds are eliminated. Light, algae, herbivorous fish, translucent building materials and a cylindrical and modular design allowed such a substitution. The integration of heating and food production freed us from dependence on technologically complex solar heating which involves collectors containing expensive copper, selective black absorber surfaces, pumps, piping and heat exchangers. Fossil fuel-burning furnaces are not used in the facility.

*Kalwall Corporation, Manchester, New Hampshire, published figures and not readings made within the ponds.

Photo by John Todd

The Ark on Prince Edward Island represents an experiment in solar design. It is intended to ask such pragmatic questions as: "Will plants grow well in a solar greenhouse in Maritime Canada?" "Is this kind of building maintainable?" "And is it a good investment, given costs, productivity and livability?" This article addresses a narrower analytic question than these but the answer hopefully will contribute to some of the more pragmatic ones. The subject of this paper is a mathematical model into which weather data can be plugged to obtain a reliable prediction of the Ark greenhouse climate variation through time. If that were all the analysis were to accomplish, it would be rather a gratuitous exercise, for the response of the real building to real weather is well measured.

Modelling is another way of understanding what is going on. The real building and its measured performance are the modeller's teachers. They gauge the mathematician's mistakes and so train the analyst. Once the model successfully "predicts" what is, in fact, known empirically, the analyst is in a better position to change parameters and make reliable statements which can be applied to buildings yet unbuilt – and about buildings that should never be built. But to say "should never..... " brings us back full circle to the pragmatic issue. An air current can accelerate leaf transpiration and promote growth by drying and inhibiting fungal colonies. It can also make us feel chilly at a temperature that would be pleasant in calm air. At a higher temperature the same air current might feel comfortable but cause water stress in a plant. Thus, pragmatic evaluation of parameter values demands a broad and context-sensitive perspective. The larger task of an analyst is to identify parameters that are at once pragmatically meaningful, measurable and subject to analysis. Part of that task consists in being in a solar building, as opposed to sitting at a desk contemplating equations.

In this paper, the model concentrates entirely on heat flow. But, before narrowing the question, I should like to consider, on a qualitative level, a sunny-day greenhouse-cycle, including heat flows, air movements, and evaporation/condensation cycles. At a winter sunrise it is cold outdoors. Heat flows by convection from various thermal reservoirs into the greenhouse air, from the soil, from concrete surfaces, and from the aquaculture ponds. A fan pulls air from the top of the greenhouse down into a rock bin, where the air picks up heat before passing back into the greenhouse through ducts along the length of the south face. The warm air rises to meet and mingle with colder air flowing down off the glazing. Heat is lost from interior air through the glazing by convection and conduction. A wind outside will partially strip the insulating air film from the glazing exterior, reducing its net insulating value in comparison to a calm day when the insulation is effective. Dependent on windspeed, infiltration of cold air through cracks around windows and doors can be another form of heat loss. Heat is also lost through radiation from warm indoor surfaces through the glazing. The transparency of the glazing to infrared light will affect this loss.

Water evaporates from the surfaces of the aquaculture ponds cooling them at a rate that is dependent on water temperature, air temperature, humidity and air movement over the water surface. There is also evaporation from soil and leaf surfaces, though at dawn these surfaces are cold and evaporation therefore is slow. The cool greenhouse air tends to be moisture-saturated, and the cold glazing is sweating. As infiltrating air displaces the moister inside air, there is both a water loss and an effective heat loss associated with the heat that was extracted to evaporate the water. Similarly, heat transferred to the glazing and out-of-doors by condensation on the glazing represents heat lost from the building. But cold air cannot carry much moisture even at saturation, so at dawn, on a winter day, evaporative heat loss will be minor.

As the sun rises and illuminates the greenhouse, some sunlight is absorbed directly into the large thermal mass of the ponds, but the majority of light will warm surfaces of low heat capacity, like loose topsoil, leaves and wood. As the morning advances, air temperatures rise quickly. Relative humidity falls as the warmed air can hold more water. Condensation stops and soil and leaf surfaces begin to dry which is probably very important in the inhibition of incipient colonies of mold and fungi. The low humidity does not persist into the afternoon, because increased evaporation from the warmed leaves and soil brings air closer to saturation. By late afternoon, relative humidity is again quite high and remains so through the night. All during the day, heat flows from the warm greenhouse air into the thermal reservoirs of the building – the soil, the concrete, the solar-algae ponds and the rock storage. By late afternoon, the direction of heat flows reverses and heat again flows from the reservoirs into the air.

Many heat flow terms could be entered into equations to describe such a system. Some terms could be made to correspond accurately to physical properties. For example, the total volume of water in the aquaculture ponds is knowable and, since the specific heat of water is known theoretically, it should be easy to calculate precisely the change in water temperature per BTU of heat gained or lost. However, following this example, the rate of heat gain or loss itself may be quite difficult to estimate, as it depends on convection currents affecting both direct and evaporative heat loss, on radiant heat exchange with many different surfaces and on heat conduction into the floor. In practice, an experimenter is unlikely to be able to measure every significant heat flow. Heat flow is harder to measure than temperature. If most heat flows are difficult to measure and to compute theoretically, how is one to know them? Herein lies the utility of dynamic simulation which makes it possible to infer difficult-to-measure values from a knowledge of measured parameters. Heat cannot be created or destroyed in significant quantities in a greenhouse, barring large-scale chemical reactions like fire. It must flow from one place to another. If a careful accounting is kept of thermal budgets, heat flows can be determined solely from temperature and insolation measurements as opposed to direct heat flow measurements. The modeller must make a guess at the parameters determining heat flow and proceed to simulate the building to be measured. Differences between the simulation and empirical measurements suggest adjustments in model parameters. At a more fundamental level, discrepancies may educate the modeller to conceptual errors in the structure of the model. The modeller can adjust and re-try the simulation until it fits the data.

A subtle question arises when the model is finally adjusted to fit the data. Do the adjusted parameters represent empirically verified values, or could there be offsetting errors which allow the simulation to work? To ask the same question at a deeper level — is tinkering with a model to make it work a way of gaining insight into real processes so that one can better predict performance in untried situations? Or is tinkering just a way of making the model trivially self-verifying but not predictive? The answer lies in mathematical bookkeeping rules known as analysis of a system's degrees of freedom. For example, how many separate thermal masses are large enough to matter, given the accuracy the modeller seeks? And how many thermal flow mechanisms are quantitatively significant? The sum of these two figures is the number of degrees of freedom of the system. Now one starts deducting degrees of freedom knowable without measurement. The known thermal capacity of a pond represents a deduction. A constraint stating that the sum of three heat flows must equal some particular value in order for energy to be conserved overall represents a deduction. After the deductions, the number of degrees of freedom remaining tells the modeller how many *independent* (i. e., those not measuring the same parameter twice) measurements are needed fully to constrain the model and keep it "honest." In practice in a non-ideal world where approximations must suffice, the application of the above rules is not straightforward. For example, the model to be derived treats air temperature as uniform when thermal stratification of air somewhat invalidates the approximation. The rules serve as guidelines in a process that relies on acquired intuition as well as science. But the wise modeller can know when to be confident of his or her system. The mark of a bad model is a multitude of terms in the equations that can be adjusted by caprice and are not verifiable either by theory or experiment.

THE MODEL

The thermal model developed and tested to date is not very detailed, due to several circumstances. First, a limited number of chart-recorded measurements are available to constrain the model, so a more detailed and precise model would be unverifiable currently. Secondly, the only computing hardware available for the simulation was a large programmable calculator (Hewlett Packard 97) whose programming and data storage capacities set an upper limit on system complexity. However, the accurate performance of the simple model is very pleasing.

Figure 1

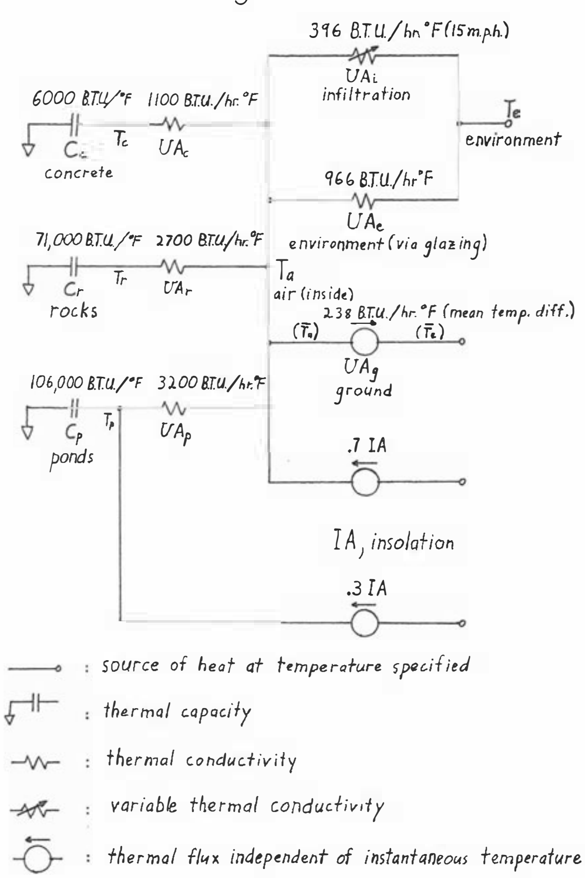


Figure 1 summarizes the heat flow paths of the model diagrammatically using the symbols commonly employed to represent electronic circuits. A grounded capacitor ( ), a device for the storage of electric charge, here represents a heat storing reservoir.

A resistor ( ) represents a path for thermal conduction offering some resistance to heat flow, although the quantity assigned to the symbol is a thermal conductivity, or reciprocal resistance. Wherever a flow of heat is imposed independent of temperature, as with insolation, a current source symbol ( ) is used. An unlimited source or sink of heat, such as the out-of-doors, is represented by a terminal labeled with an imposed temperature ( ). The diagram specifies all the relationships between temperature, wind, sun and heat flow that are in the mathematical model. A few rules on such questions as "how to determine insolation" are explained later in the text.

The simple system contains only three effective reservoirs of heat, each characterized by a total capacity C BTU/$^\circ$F, a ratio of heat gained or lost (BTU's) for each degree of temperature change (/$^\circ$F). The three reservoirs are the aquaculture ponds (Cp = 106,000 BTU/$^\circ$F), the rocks in the storage bin (Cr = 71,000 BTU/$^\circ$F), and exposed concrete (Cc = 6,000 BTU/$^\circ$F). Only concrete down to an effective depth of thermal penetration of 4.2 inches and not the whole mass of foundation concrete is included in Cc. In fact, thermal penetration depth is time period dependent, and representation of Cc as a single parameter is an approximation valid only for periods from a few hours to a couple of days, not for very short or long periods. Greenhouse soil was presumed to contribute little effective capacity because loose surface soil holding dead air would insulate the underlying soil mass. Likewise, all the small thermal masses of plants, benches, paint cans, etc., were ignored. The effect of these omissions on the short-term performance of the simulation will become evident.

With each heat reservoir there is an associated heat conductivity constant UA coupling the reservoir (at Tc or Tr or Tp) to the greenhouse air (at Ta). In some cases, UA represents the product of a per unit area exchange constant, U BTU/hr. ft.^{2}$^\circ$F, and an associated area A. In other cases, where heat exchange is through an air flow, as with the rock storage, UA represents the product of heat capacity per unit volume multiplied by a volume per time flow rate. In either case, UA has units BTU/hr.$^\circ$F and represents net conductivity, the ratio of heat flow (BTU/hr.) to temperature difference (/$^\circ$F). In the case of the ponds, UAp represents the combined contributions of convection, conduction and radiation. Evaporation, the thermal effect of which is highly dependent on temperatures and air movements, is ignored. Ballpark calculations indicate that evaporative thermal effects should be small for the cool wintertime greenhouse temperatures under study, but this would not be the case in a warmer climate or in a heated greenhouse. For concrete, UAc includes surface airfilm convection resistance, an effective bulk thermal resistance (dependent on depth of penetration) about equal to airfilm resistance, and a radiative surface term. Technically, radiant heat does not heat greenhouse air, as modelled, but instead heats surfaces that absorb the radiant flux. The model is based on the assumption that most surfaces absorbing radiant heat have little absorption capacity and quickly change temperature to transfer radiative heat gain or loss to the air via convection. Thus, the intermediate step of radiant heat warming the air through objects is ignored.

Greenhouse air loses heat to the outside by three main paths. UAg represents loss by conduction and radiation through the glazing. UAi, expressed in units BTU/hr.$^\circ$F x 15 mph, presumes a linear dependence of infiltration loss on outside windspeed relative to a 15 mph architectural design windspeed. In fact, infiltration depends partly on pressure differences caused by buoyancy of warm indoor air. It varies typically as the .7 power of windspeed, rather than linearly. But the value for UAi is a crude estimate with no empirical verification, such as trace gas dilution measured over time, so a more complex representation of infiltration effects is hardly justifiable. Finally, a rate of heat loss (UAg) through the ground is presumed to depend only on long-term soil temperature gradients based on weather over a month. Thus, UAg is multiplied by the long-term average temperature difference. In effect, shorter term variations in ground loss are incorporated into the concrete terms UAc and Cc.

The final term in the equations is an insolation flux IA, computed from an insolation per unit area equation I and a glazing area A. IA is split into two components: 30% is absorbed directly into the aquaculture ponds, while the remaining 70% heats greenhouse air "directly", which means that the sun falls on and quickly heats surfaces of low thermal capacity which, in turn, pass the heat on to the air by convection. Corrections for angle of incidence, atmospheric absorption, glazing reflection and reflection of light back out of the greenhouse are taken into account, as will be described later. The current program computes insolation only for completely clear days, for which the angle and intensity of light are derivable from straightforward formulas. The Prince Edward Island Ark has lacked sufficient insolation monitoring equipment to allow for the measurement of angles of incidence of cloud-scattered light. Also, transfer of the jagged insolation curves of cloudy days into the calculator would be inaccurate and time-consuming. Therefore, only days of full sun have received intensive analysis. Simulation for cloudy weather will await computer monitoring.

In computing simulated system performance, values for outside environment air temperature Te and windspeed come from chart-recorded data from a clear day. Later, with sufficient monitoring, insolation

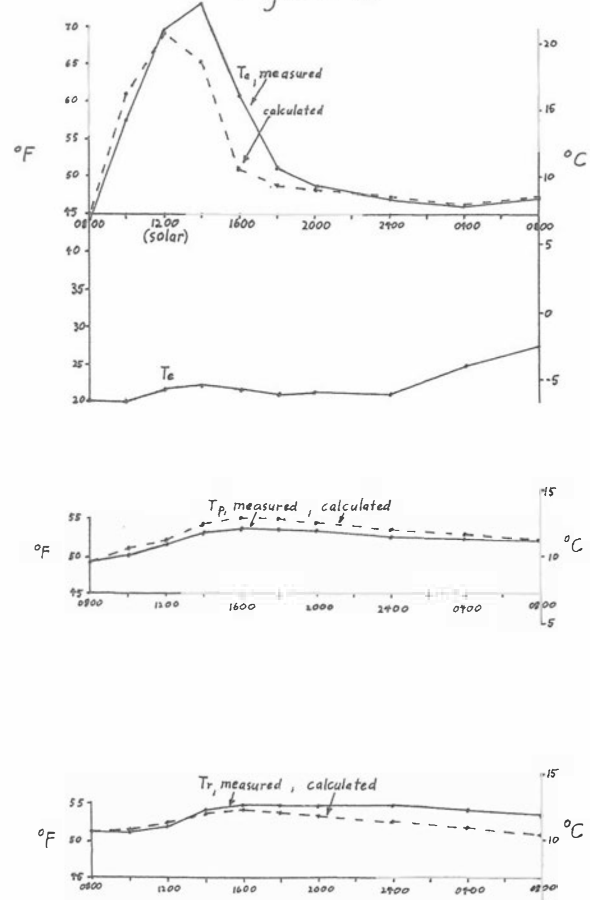
Photo by John Todd

also will derive entirely from measurement rather than from formulas for clear days. Heat reservoir temperatures are initially set to measured values. Air temperature is computed as that temperature at which all heat flows into and out of the air exactly balance to zero net. Thus, heat capacity of the air itself is ignored, an assumption causing errors for very short-term phenomena only. Once Ta is computed, rates of heat flow into the reservoirs can be determined. This, in turn, gives a time rate-of-change for the three reservoir temperatures. The program then extrapolates temperatures ahead six minutes. At this point, ambient temperature, infiltration, insolation and air temperature are all recomputed in preparation for the next six-minute extrapolation. Thus, we obtain a more or less continuous plot of temperatures over time that can be compared with actual measured temperatures.

A comparison of computed and measured temperatures for December 27, 1977, is plotted in Figure 2. Concrete temperature Tc is not plotted since it is not measured, though it was computed. Note that the precise match of Tp and Tr at the beginning of the simulation results from initialization of those parameters to match measured data. However, the close match between measured and calculated air temperature is non-trivial, representing, as it does, a balance among computed heat flows. We see that actual air temperature does not begin to drop as quickly in the afternoon as computed air temperature. This error is probably due in part to the mathematical omission of many small thermal masses having short-term effects. The simulated rock storage response to changing air temperature follows measured rock temperature closely until computed air temperatures, which determine rock temperature variation, begin to diverge from measured values. Aquaculture pond variation is quite close. At the end of the simulated day, total heat gained and lost from the simulated reservoirs comes very close to matching the measurements, a strong indication that the model will work well for extended simulation periods without large cumulative errors. Note that the parameters used in this simulation were in no way corrected to make the simulation fit the data. They represent before-the-fact estimates. It would not be valid to adjust this simulation to make it fit, for there is insufficient measured data to validate or invalidate adjustments in system parameters by the degrees of freedom criteria discussed earlier.

There are a few interesting "instantaneous" response characteristics to the model, such as behaviors

Figure 2



which have no time lag in the model and very short time lag (5 minutes to 30 minutes) in the actual system. When a cloud passes in front of the sun, greenhouse temperature drops very rapidly and begins leveling off with a dominant time constant of about 6 minutes. This corresponds to an instantaneous change in the model. As to the magnitude of the temperature change, the model predicts:

$\triangle Ta$ = .7 IA/(UAp + UAr + UAc + UAe + UAi)
= .7 (254,000 BTU/hr.)/(8,362 BTU/hr.°F)
= 21.3°F or 11.8°C, computed at noon on the winter solstice with a 15 mph wind blowing.

Precise corroboration of this figure from data is not possible because of thermal time lags not included in the model, but observable temperature changes within 20 minutes of a large change in insolation due to clouds definitely fall within 20% to 30% of the predicted range. When outdoor temperature changes abruptly, the greenhouse air temperature should immediately change by the fraction (UAe + UAi)/(UAp + UAr + UAc + UAe + UAi) = .163 times as much. This fraction has another significance. When sunlight is absorbed by the building, the "instantaneous" temperature rise inside causes the fraction .163 of that absorbed energy to be lost with no delay. The remainder enters the thermal stores, although this fraction does not apply to the 30% of insolation going straight into the aquaculture ponds.

Comparing thermal capacities, the contributions are: from the ponds, 58%; from the rocks, 39%; from exposed concrete, 3%, for a total capacity of 183,000 BTU/°F. Note that the ratio C/U has units of hours. This ratio is a time constant which expresses how rapidly an existing temperature difference would be reduced to zero if temperature continued to change at a constant rate. In fact, rate of change of temperature decreases in proportion to the remaining temperature differential, so that after one elapsed time constant, the temperature difference is reduced by the factor 1/e = .368, where e is the base of the natural logarithms. More familiar to some will be the decay half life, commonly related to decrease in natural radioactivity.

Half Life = Time Constant x Ln(2)
= Time Constant x .693.

Equilibration time constants of greenhouse storage media with air temperature are: ponds, 33 hours; rocks, 26 hours; concrete, 6 hours.

We have considered time constants of equilibration for separate thermal reservoirs with greenhouse air. There are also three time constants associated with the reduction in amplitude of specific patterns of temperature difference within the greenhouse as a system of interacting parts. The patterns of temperature difference are known as eigenvectors, and the reciprocal time constants associated with each eigenvector are known as eigenvalues, after the terminology of linear systems analysis. For the Ark greenhouse model, the reciprocals of the eigenvalues are 6 hours, 29 hours and 164 hours. The 164-hour time constant is of particular interest. Its associated eigenvector shows all three thermal reservoirs remaining at almost equal temperatures while they collectively equilibrate with the outdoor environment with a 164-hour time constant. Thus, we have an excellent measure of how fast the total system equilibrates to outdoor temperature when the sun fails to shine: large changes take about a week.

DETAILED PARAMETER DERIVATIONS

The C and UA parameters of the analysis were derived as follows. For Cp, each pond is a translucent cylinder 4 feet in diameter and filled to about 4.5 feet in depth, giving a volume of 56.55 ft.^{3} per pond. With water density = 62.4 lb./ft.^{3}, that yields 3,529 lb. per pond, or about 106,000 lb. water, total, for 30 ponds. The specific heat of water is conveniently 1 BTU/lb.°F, so immediately Cp = 106,000 BTU/°F.

For UAp, a starting point is the surface area of the pond tops and sides, but not bottoms, which are insulated to contribute negligible heat flow. The result is 22π ft.^{2} per pond, or 660π = 2,073 ft.^{2} for all 30 ponds. Heat exchange between the ponds and the rest of the greenhouse has convective and radiative components. The ASHRAE Handbook of Fundamentals is helpful here. In Chapter 20, we learn that a typical radiative contribution to surface conductance, f, is roughly .7 BTU/hr. ft.^{2}°F for surfaces with high infrared emissivity. The Kalwall ponds should have fairly high emissivity despite low emissivity in parts of the infrared spectrum for the glass in the Kalwall. However, most of the ponds are flanked by neighbors on two or three sides, and radiations emitted by one pond only to be absorbed by another pond do not represent energy exchange from the system of all the ponds to the surrounding greenhouse. As an estimate, therefore, 30% of .7 BTU/hr. ft.^{2}°F will be deducted from the overall f value given in the ASHRAE graphs. Convective heat transfer is windspeed dependent. Watching cigarette smoke drift over the ponds gives a windspeed estimate of roughly 1 mph. With that value, and for smooth surfaces, the graphs in ASHRAE give roughly f = 1.8. That value drops to f = 1.59 after deducting 30% of .7 BTU/hr. ft.^{2}°F as discussed. Finally, the manual indicates that f factors decrease for increasing scale of objects above the 1 ft.^{2} size of the samples used to derive their graphs. So the value f = 1.54 was finally chosen. Finally extending f over 2,073 ft.^{2} yields UAp = (2,073)(1.54) = 3,200 BTU/hr.°F.

Cr is derived starting from figures from the *Energy Primer* (Portola Institute) of basalt density = 184 lb./ft.^{3} and specific heat = .2 BTU/lb.°F, giving 36.8 BTU/ft.^{3}°F of solid basalt. Since basalt is very dense rock, the heat capacity of typical concrete is averaged in: 144 lb/ft.^{3} with specific heat = .22 yields 31.7 BTU/ft.^{3}°F. The guess was that rocks quarried in Nova Scotia and trucked to the Ark have a volumetric heat capacity precisely equal to the average of *Energy Primer* basalt and Frank Brookshire's (the source of 144 lb./ft.^{3} and .22) concrete, or 34.25 BTU/ft.^{3}°F. These calculations are for solid rock. A little geometry shows that for spheres packed in cubic symmetry, solidity is $\pi/6$, while for close packed spheres with tetrahedral symmetry, solidity is $\pi\sqrt{2}/6$. The two-digit number nearest the mean of these two solidities is .63, leaving 37% air space, which intuitively sounds reasonable for randomly-packed stones of varying size and shape. The architect's estimate of volume occupied by rocks is 118 yd.^{3} = 3,186 ft.^{3}. Multiplying by (.63)(34.25 BTU/ft.^{3}°F) yields Cr = 69,000 BTU/°F. This figure is upped slightly, to Cr = 71,000 BTU/°F, to include a contribution from the concrete walls of the bin. We might note in passing that (.63)(34.25) = 21.58 BTU/ft.^{3}°F for rocks compares with 62.4 BTU/ft.^{3}°F for water, such that rocks are volumetrically 35% as efficient as water for heat storage.

Architects David Bergmark and Ole Hammarlund estimate a rate of flow of 2,500 c.f.m. through the rocks, based on duct geometry and blower specifications. Heat capacity for air is .018 BTU/ft.^{3}°F. If we assume that the full 2,500 c.f.m. flow reaches thermal equilibrium with Cr, we easily derive UAr = (2,500 ft.^{3}/min.)(60min./hr.)(.018 BTU/ft.^{3}°F) = 2,700 BTU/hr.°F. Empirically, temperature traces on our charts show no vestige of short-term temperature fluctuations in air emerging from the rock storage, a strong indication of near complete equilibration of the air with the thermal mass. But an analytic verification of equilibration leads to a very interesting general result about design of rock storage.

If we suppose, for purposes of computing surface to volume ratio, that the rocks behave like eight-inch spheres, which approximates a typical size, then (surface area/volume = 9 ft.^{2}/ft.^{3} of solid, or (.63)(9) = 5.67 ft.^{2} per ft.^{3} of volume of the rock container. That gives 18,000 ft.^{2} over 3,186 ft.^{3} If we assume a surface conductivity f = 1.5 BTU/ft.^{2}hr.°F (based on ASHRAE graphs, as used to compute UAp above, and recalling that radiative heat transfer from stone to stone contributes nothing to rock-to-air heat exchange), then we get UA = f(18,000 ft.^{2}) = 27,000 BTU/hr.°F. The heat capacity of the air in the rocks is .018 BTU/ft.^{3}°F in 37% of 3,186 ft.^{3}, or 21.2 BTU/°F net. Dividing this heat capacity by 27,000 BTU/hr.°F yields a time constant of .00117 hours for air equilibration with the rocks. For how long does the air pass through the rocks? Dividing 2,500 ft.^{3}/min. into 37% of 3,186 ft.^{3} yields .472 minutes or .00786 hours and, comparing this with the .00117 hour equilibration time constant, we see that the air spends 6.7 equilibration time constants among the rocks, implying equilibration to within roughly .1% of rock temperature!

There is one consideration still to be checked: Although air in the rock storage reaches thermal equilibrium with the rock surfaces, thermal resistance from rock surface to interior is not significant. Thermal conductivity of stone and concrete is roughly k = 10 BTU/ft.^{2}hr. (°F/in.) (see ASHRAE handbook), or in 2 inches, which is halfway from a stone's surface to its center (and penetrates 7/8ths of the volume), we get k/2 in. = 5 BTU/ft.^{2}hr.°F. This conductivity is high compared to f = 1.5 BTU/ft.^{2}hr.°F for the surfaces, so we conclude that, for these size stones or any stones under roughly two-foot diameter, thermal resistance from the stone's surface into its mass is unimportant.

Arguments like the above were used to derive a formula for maximum typical rock size to allow at least 90% equilibration of air with rocks in a thermal store. Allowing a factor-of-two margin for non-uniform air flow through portions of the rock store, the relation is dmax = 12 V/F, for d = diameter in inches, V is volume in ft.^{3}, and F is flow rate in ft.^{3}/min. V/F is simply a nominal air transit time in minutes, neglecting volume occupied by rocks. For dmax exceeding 24 inches, rock size smaller than given by the formula could be required. For the Ark greenhouse store, the formula gives dmax = 15.3 inches. The results of this formula are likely to arouse controversy from advocates of fist or golfball or pea gravel size rocks. We would argue that subdivision of rocks below dmax has negligible effect on total thermal capacity or heat exchange, but very small rocks filling a bin will offer considerably more resistance to air flow through them.

Perhaps the parameters most difficult to argue in the model are the concrete parameters Cc and UAc. The values given happen to correspond to the thermal response of typical concrete to sinusoidal ambient temperature fluctuations with a period of 16 hours. The calculation assumed concrete with a volumetric heat capacity of 31.7 BTU/ft.^{3}°F and volume conductivity k = 9.1 BTU/ft.^{2}hr.(°F/in.). Solving the partial differential equations for heat flow in a solid one-dimensional medium gives the same heat-flow magnitude and phase for 16-hour periodicity that would be given by 1/U = .65 hr.ft.^{2}°F/BTU and C/A = 3.9 BTU/ft.^{2}°F. Adding airfilm resistance .68 gives a total of 1/U = 1.33 or U = .75 BTU/hr.ft.^{2}°F. Extending the above quantities over 1,500 ft.^{2} yields UAc = 1,125 BTU/hr.°F, which was rounded to 1,100, and Cc = 5,850 BTU/°F, which was rounded to 6,000. For periodicities other than 16 hours, airfilm resistance remains the same while effective conductivity U increases as $\sqrt{\text{frequency}}$ and capacity C/A decreases as $1/\sqrt{\text{frequency}}$. Using these relations, the correct magnitude and phase of thermal resistance into concrete can be compared with the magnitudes and phases for fixed UA and C. The amplitude ratios of the approximation divided by correct value, and the phase differences, are tabulated:

period (hrs)	*approximate amplitude* / *correct amplitude*	*phase error (°)*
1	1.57	9.5
2	1.43	11.1
4	1.27	11.3
8	1.12	8.5
16	1.00	0
24	.98	- 8.0
48	1.11	- 23.9
96	1.49	- 36.2

Since the concrete is a minor contributor to thermal inertia, especially for periods well above the six-hour characteristic time constant of the approximation, the above correlation seems to justify the approximation used.

Heat loss into the ground, as expressed by UAg = 238 BTU/hr.°F, was determined assuming conductivity of both concrete and subsurface soil at k = 9 BTU/ft.^{2}hr.(°F/in.). The difficulty is that the heat path is not one but three-dimensional. Ignoring the corners of the greenhouse, one can approximately solve heat flow through the concrete walls and earth as a two-dimensional heat flow problem. The method in this analysis was to use the flow of electricity through conductive (teledeltos) paper as an analog for heat flow through soil. Silver paint was brushed onto the paper to define boundaries of thermal contact of either inside or outside air with soil or concrete. Dimensions of the conductive paint drawings were adjusted slightly to account for airfilm resistances. The outcome was two carefully-drawn conductive shapes separated by an area of conductive paper. Resistance between the two paint electrodes was then measured with an ohm meter and ratioed to the resistance of a reference square of the same conductive paper. Suitable scaling from this resistance ratio gave a thermal conductivity per unit length of the greenhouse wall. Multiplying this figure by the appropriate wall length and repeating for a differing foundation shape on the end and opposite side of the greenhouse gave rise to the final value of UAg. Those familiar with Laplace's equation will recognize in the above description an analog solution that could also have been found by digital computation, a more common approach.

Heat loss through the glazing was computed directly from U = .58 for the Rohaglas glazing extrusion, using the manufacturer's data for winter conditions, and 1,665 ft.^{2} of glazing, total. The architects calculated infiltration using standard formulas, based on a 15 mph windspeed and scaled linearly to measured windspeed for this model.

In the current program, insolation can be computed only for clear days. We currently monitor solar flux only in the horizontal plane so the effective angle of sunlight relative to the glazing can just be computed

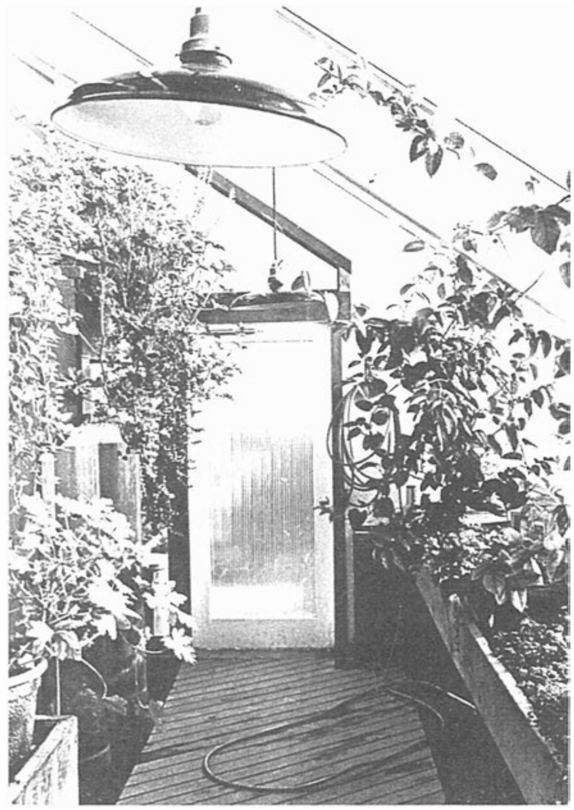


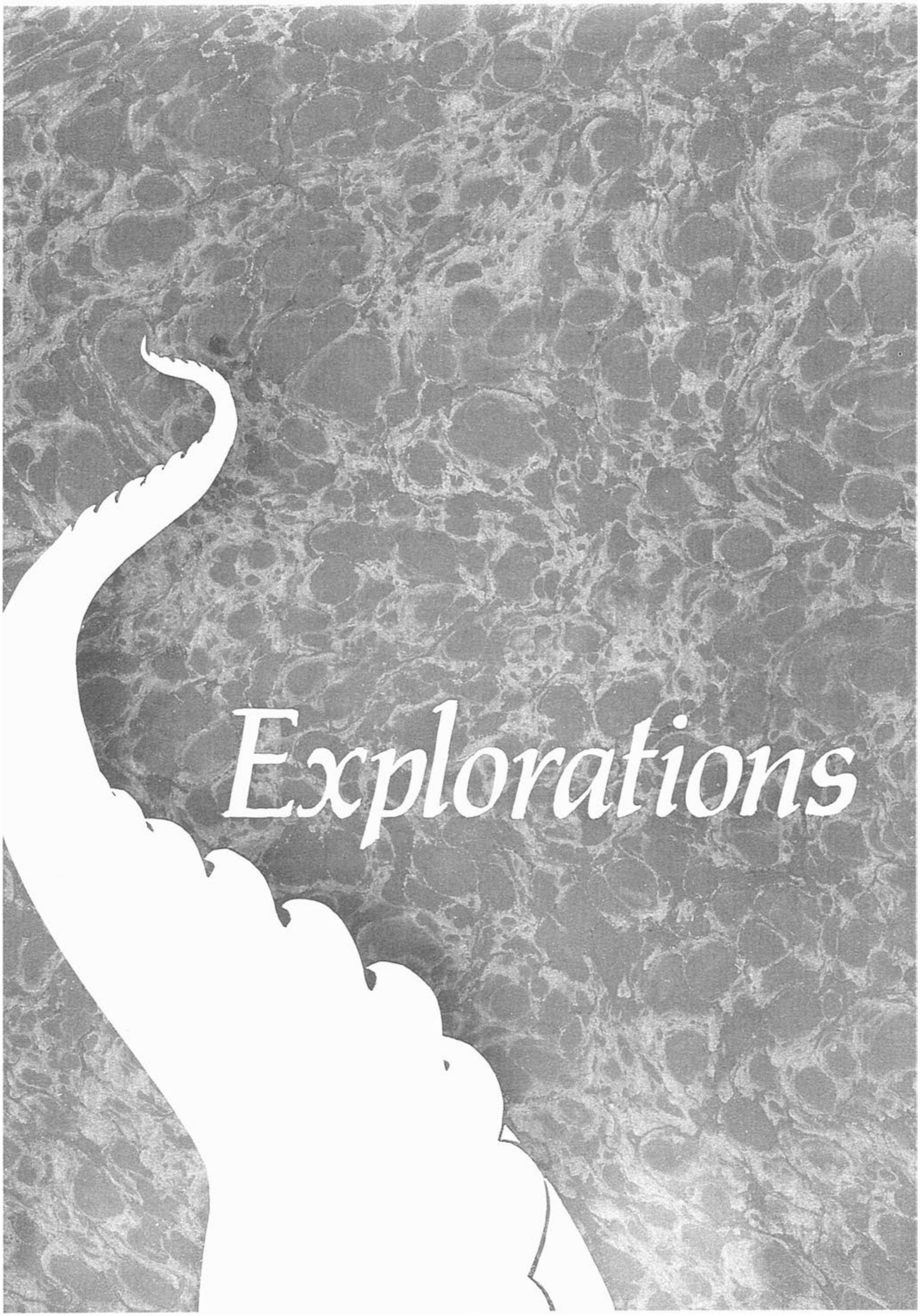
Photo by John Todd

for clear sky. Insolation is divided into two components, diffuse and direct. Formulas for both are derived from graphical data found in the *Energy Primer* for intensity versus sun angle from the horizon. Taking θ as the angle of the sun down from straight overhead, then outdoors I diffuse = $38(1-(\theta/90)^6)$ BTU/ft.^{2}hr., and I direct = $315(1-(\theta/90)^6)$ BTU/ft.^{2}hr. θ is calculated from celestial trigonometry. For diffuse light, the following corrections are applied. The average slope of the greenhouse roof, taking the chord beneath the Rohaglas glazing and the double-glazed glass windows, is 39° out of the horizontal. This implies a loss of diffuse light from the north sky. For the remaining sky visible by the roof, an integration was performed to determine mean reflection by the glazing, using the transmission formula Transmission Fraction = $.8(1-(\Phi/90)^{4.5})$, for Φ degrees between incident light and glazing normal. This formula was empirically fit to tabular data from the *Energy Primer* and Rohaglas data. Next, a correction was made assuming more diffuse light comes from the southern than northern sky. Finally, of the diffuse light penetrating the glazing, 10% reflects back out. This albedo correction is based on light meter measurements. With all these corrections, we have I diffuse, net = $18(1-(\theta/90)^6)$. Corrections for I direct depend on angle Φ, the angle between the glazing normal and time-dependent sun angle. After corrections, we have I direct, net = $(.9)(.8(1-(\theta/90)^{4.5})(\cos\theta)(315(1-(\theta/90)^6))$, where .9 is the same albedo correction used for diffuse light, the next term is transmission of the glazing versus angle, and the last correction is a simple geometry correction for sunlight intercepted. The above formulas can be applied to a horizontal plane and correlated against insolation data from our charts. The measured insolation during November 1977 was 5% more than the outcome of the above, a discrepancy as yet unexplained.

CONCLUSION

The large fraction of effective thermal storage provided by the translucent aquaculture ponds is particularly provocative when the large electric power backup cost to guarantee rock storage circulation is considered. While the rock storage has provided an indispensable but minor portion of thermal storage, without which plants might have frozen, it should be asked what system modifications might eliminate the need for rock storage. Raising the rear aquaculture ponds to intercept more direct sunlight would hold down peak temperatures and increase net thermal retention. Forced convection in free greenhouse air would use far less energy than is used in forcing smaller quantities of air at high speed through ducts. Low speed, large diameter blade fans could break thermal stratification, increase airfilm U factor for the ponds and require only 20% or 30% as much electricity. Finally, a simple closeable night-time shade system would easily upgrade heat retention. It would use less energy and in future systems require less capital.

A final note of caution about insulating a greenhouse too well: plants must transpire considerable quantities of water. If insulation glazing that is too tight is coupled with substantial reduction of infiltration, humidity could become a serious problem. A major benefit of good modelling would be to give estimates of humidity as well as thermal consequences of proposed greenhouse designs.



Explorations

Photo by Hilde Maingay

The dimensions of time and space explored in the two articles in this section are, as always, various. Bill McLarney's writing is on the subject of "The Future of Development in Latin America." Through his experiences and his work there over the past seven years, characteristically, he has acquired strong opinions, considerable insight and some very workable and humane theories as to how development might proceed equably. His perspective is not that of the casual visitor. He lives and works on the N.A.I.S.A. farm in Gandoca in Costa Rica for several months each year and is deeply involved with and committed to the community there. Unlike so many theorists he does not embrace a single strategy to allay worsening conditions by concentrating exclusively on immediate human needs at the expense of the environment or of peoples to come, nor does he, in a rush of ecological enthusiasm, advocate sweeping land reforms that would displace populations. His respect for indigenous peoples is perhaps the most compelling quality of his article and accounts in part for the quality of his relationship with his own community.

Turning from Latin America in the final quarter of this century, the article by Meredith Fuller Luyten looks backward to Provence in the last. As she explains, her interest in the French naturalist, Jean Henri Casimer Fabre, has been a long one. One of his attributes that occupied her was the quality of his perception, his ability to watch and become absorbed, even a part of the creatures he observed and loved — to internalize his environment. As have many other naturalists, Fabre added incalculable riches to our knowledge and understanding of the world. His strong sense of place is echoed in contemporary writers like Wendell Berry and Annie Dillard. It was the uniqueness of his perception, his intuitive grasp of what Gregory Bateson calls "the pattern that connects", as Meredith describes it, that made her article so well suited to this issue of the Journal.

Meredith's poems have appeared in the second, third and fourth Journals. She lives near New Alchemy on the Cape and currently is working on a novel.

— NJT

Future of Latin America

– William O. McLarney

With due deference to Stewart Brand's dictum about the "talk-do ratio" and having, as I start to write, just finished several months of heavy duty doing in Costa Rica (see Page 18), I intend to talk a little about "development" in the future of Costa Rica and Latin America. There is, in Costa Rica at least, no shortage of foreign and national agencies, institutes and individuals dedicated to one or another activity intended to help "develop" the country. For purposes of this essay, we shall consider only those whose interest is sincere, excluding those for whom "development" is just a cloak to veil political or profit-oriented activities. I further intend to confine my thoughts to the rural situation.

Even with the exclusion of all the charlatans and urban workers, the "development" and "aid" people sometimes seem to outnumber the ordinary citizens. To forestall any charges of caricature, let me affirm that each of these people is an individual with his or her own blend of wisdom and folly. I never seem to run into anyone I totally agree or disagree with about the future of rural Latin America. For the sake of argument, though, I think it is not unreasonable to place the various groups and individuals working in the area in two categories – the "people-first" wing and the "ecology-first" wing. I find myself partially at odds with both factions, but let me begin by admitting my areas of broad agreement with each.

The "people-first"folk are usually concerned with some aspect of food. They are absolutely right in pointing out the folly of Latin American nations giving economic priority to export crops when many of them do not begin to produce enough food for their own people. They see poverty and the disparity between Latin American and North American standards of living. They see a malnourished child as a cry for action – and so it is. Their concern with land is usually focused on land reform. The child cannot be nourished by the coffee, sugar, bananas or beef grown in Latin America and shipped to the overdeveloped countries. "People-firsters" work to bring food, land and employment to the people.

The "ecology-first" people have read history. They know our species' deplorable record as a despoiler of soils and ecosystems. They see the malnourished child as the symptom of bad land use, perhaps by its own parents. They act from a love of the natural environment which, if professed and practiced by every landowner, would *be* the solution. They work as conservationists, trying to save watersheds from drying up, hillsides from eroding, forests from burning.

The ecology people, in some of their more extreme manifestations, seem to view the campesino as a madman with a gun in one hand and an axe in the other, bent on destroying every wild creature in sight. The more land they can fence him out of, the more secure they feel.

The people-first wing, on the other hand, has a tendency to forget about future generations in its rush to aid those who are here now. Their romanticized view of campesinos as peasant revolutionaries who will somehow set everything right if just given enough land to work is as unrealistic and unfair as its opposite.

It is a political, economic and social fact that there is a dire need for land reform in much of Latin America; too much land in the hands of too few people is always a bad situation. It is also a fact that much of campesino agriculture, as practiced today, is deplorably shortsighted and ecologically abominable.

Are we then faced with a true dilemma? It is socially and humanly unacceptable to force the rural people of Latin America into permanent dependence on export crops, peon labor and "La Compania." It is ecologically unacceptable to allow the last forests of the region to be burned, the topsoil to be washed into the sea and the watersheds to be dried up. Yet it might seem that these are the alternatives.

I can already hear the clamor of voices of the development and aid folk, along with the businessmen and government people, offering opinions, solutions and defenses. We shall listen to their opinions – some of them have something to teach. Somewhat more space will be devoted to my own strongly held opinions. But one should keep a grain of salt handy, for all of these estimable folk, whatever their experience and wisdom, manage to survive without recourse to axe, gun or plow.

So, I shall spice the stew with yet another set of opinions – those of campesinos. Whatever they have to say, it should prove interesting, for they are seldom asked their opinions about the future of rural Latin America. They just live there.

Lest anyone think it is simple to get a grasp of the situation, let me begin by offering a few informational items of recent vintage about Costa Rica.

ITEM: Costa Rica has 19,650 square miles of land and 1,921,000 people, according to the 1974 census, for a population density of 97.7 per square mile, second in mainland Latin America only to El Salvador's 473.8 inhabitants per square mile. Land distribution, while certainly a problem, is generally more equitable than elsewhere in the region. The standard of living is among the highest in Latin America and, by such other conventional indices of well-being as health, education and literacy, the country rates high.

Until very recently Costa Rica had the second highest population growth rate in the world, but currently a birth control campaign seems to be having an effect. Nevertheless, the population continues to grow, while in recent years the economic and nutritional well-being of the country has declined.

It is probably fruitless to debate the precise nature and importance of the relationship between population growth and national well-being. Nevertheless, I was appalled last year to hear a North American friend, resident for many years in Costa Rica, assert to a group of campesinos that, with land reform, Costa Rica would support fifty million people.

Perhaps, given certain conditions, such a feat could be shown to be biologically and economically "feasible", but what of the quality and diversity of the natural environment and the traditional rural lifestyle? Would anyone believe land reform *and* population control?

ITEM: Costa Rica has the best national park system in Central America. At a meeting in Puerto Limón in 1976, attended by campesinos from all over Limón province (the least densely populated of Costa Rica's seven provinces) there was open discussion of the best tactics for invading and colonizing Tortuguero National Park.

ITEM: Costa Rica's highest mountain is Chirripo (elevation 3819 meters) which lies in the wilderness of the Talamanca Range. Chirripo forms a large part of the watershed of the Sixaola, General and Matina drainage basins, major sources of the nation's water and electrical power. For this reason, the slopes and environs of Chirripo were declared a forest preserve, with all clearing and cutting forbidden. In 1976, part of the forest was deliberately set afire and many acres destroyed.

Costa Rican campesinos traditionally have had the right to homestead public land. The motive for setting the fire would appear to be as a protest against losing the area to colonization. (And, of course, once cleared by fire, it makes little sense to call the area a forest preserve.)

ITEM: A disproportionate number of acres of good agricultural land in Costa Rica are held by multinational companies such as United Brands, Standard Fruit, Hershey Chocolate, etc. Some of their land is in production, some has never been touched. There are also extensive holdings, which, though cleared, have not been worked for up to twenty years. In one such area procedures are now underway to evict "squatters" from their farms. If these people do not choose to become peons for "La Compania" the nearest "available" lands are the forest preserves and Indian reservations of the Talamancas.

ITEM: Some of the agricultural companies do all they can to discourage their workers from planting crops of their own. They have been known on occasion to go so far as to buy land for the sole purpose of suppressing production of indigenous food and cash crops. In the town of Siquirres, Standard Fruit fosters yet further dependency. There, many tons of bananas are thrown in the river every year because of blemishes and/or to keep the price up. Every precaution is taken to ensure that the local people do not take advantage of any free bananas.

ITEM: A friend of ours, a young and ambitious Gringo, who considers himself ecologically concerned and informed, has a small and very well managed farm in a coastal region of Costa Rica. He has learned tropical agriculture the hard way – by doing it. His income is certainly beyond that of the average campesino farmer but, feeling the need to supplement it, he recently landed a job as a consultant for one of the major agricultural companies. He is working on a project involving 20,000 acres of virgin forest near a settled area which the company recently purchased from the Costa Rican government. Our friend explained that the company got the land just in time before squatters moved in and "ruined" it. The land is to be clearcut and planted to monocrops which will not be consumed by Costa Ricans.

The primary "use" of land is to sustain people; people are to sustain land. For me, the common thread which runs through the confusing series of anecdotes I have just related is that, in each case, this seemingly simple relationship has been confused, perverted or lost sight of altogether. But modern Costa Rica affords at least one more spectacular example of flagrant disregard of the people/land relationship. I refer to the plains of Guanacaste

Guanacaste Province comprises the northwest corner of the country. Much of it consisted originally of a fairly fertile plain favored with spring-fed rivers and moderate rainfall. With settlement, the plain became a patchwork of forests and farms and a major producer of food for Costa Rica. Then came cotton, a notorious consumer of soils. Following the boom and bust of cotton, the entirety of the lowlands of Guanacaste was converted into cattle pasture to help satisfy the insane appetite of North Americans for cheap, tasteless hamburgers. Between 1970 and 1972, over one and one-half million acres of Guanacaste land were sold to North Americans, primarily for conversion to cattle pasture.

What has this meant to Costa Rica? From being one of the country's greatest assets, the Guanacaste plain has become a drain on its economy. During the 60's, Costa Rican beef production increased by 92% while per capita meat consumption declined by 26%. The nation has had to increase imports of beans, rice and corn as a result of the removal of Guanacaste cropland from production. The plains of Guanacaste have been depopulated, as small farmers have sold out to the cattle interests. A few families stay behind to work as peons. Others contribute to the growth of urban slums. Many move on to clear and settle land far less suited for traditional campesino agriculture than the plains they left.

Today Guanacaste has the poorest nutrition, the highest infant mortality, the greatest incidence of alcoholism, etc., etc., of the seven provinces. Even those individuals, Costa Rican and foreign, who profited initially are beginning to suffer. The wholesale clearing of forests and conversion of land to pasture has altered the climate. The dry season, which previously lasted three or four months, now goes on for eight or nine, maybe more. In the drought of 1975-76, cattlemen were selling their animals at a loss. Cattle dying by the roadside were commonplace.

Perhaps a quarter of the lowlands have been transformed into a true desert and the whole region is in trouble. The ecological destruction is virtually complete.

Who is to blame? In a small way, one can fault the campesinos, or at least the first few, who, shortsightedly, sold their fertile lands before the drought years. But the ecologically stupid policies which led to the final destruction of the Guanacaste plains were created and promoted by people who sit in offices in San José and abroad.

This is not to say that campesinos never contribute to the physical destruction of resources. One such case was narrowly averted last year when the former president, Daniel Oduber, had the foresight to exercise his powers in a rather controversial manner by declaring a large part of the Osa Peninsula a "disaster area" before the actual occurrence of the disaster. The Osa Peninsula, in the southwest corner of Costa Rica, is the last wilderness on the Pacific slope of Central America. Its western half is characterized by steep slopes, dense forest and heavy rainfall. It is simply not agricultural land. Stripped of its forest, it *might* yield crops and profits for five years or so, after which erosion, leaching, landslides, etc., would render it virtually sterile, as has already happened in similar areas in Panama. As of a few years ago, homesteaders were beginning to chop their way into the hills of the Osa. It is to the credit of President Oduber, Alvaro Ugalde, head of Costa Rica's National Park Service, and their ecologist advisers that they blew the whistle, bought out those squatters who had already moved in, and created the 72,000 acre Parque Nacional Corcovado.

Two episodes in the ecological history of Costa Rica: It may be instructive to ask why the ecologists were powerless against the destruction of the Guanacaste plain by business interests seeking a few years' profits, but succeeded in preventing the destruction of Osa by campesinos hoping to earn a subsistence.

While thinking about that, it may also be instructive to try to view both events through campesino eyes. (Be assured that some of the people who tried to settle the Osa were the same ones who had left Guanacaste.) (It may seem unfair to lump ecologists and assorted cattlemen and business people together just because of economic class. But to a campesino we are pretty much the same – upper class "outsiders" who tell him what to do.) We seem to have kicked the campesinos up into the hills and then kicked them off because they threatened to knock a little dirt down on us.

It would be tragic if campesinos were to become totally alienated from the ecology movement, but there is a tendency to regard ecology and resource conservation as the playthings of those who can afford to buy all their food. This is exacerbated by the ecological tokenism practiced by some large commercial interests. The beaches of the Nicoya Peninsula will serve as an example. The coast of Nicoya is among the most beautiful parts of Costa Rica. The clean, clear blue Pacific breaks on pockets of white sand artfully tucked away between steep rocky cliffs. The vegetation and water temperature are tropical, but otherwise it is reminiscent of northern California. The beaches are, of course, being "developed", principally for foreigners. In some places, Costa Ricans have been denied access to their own beaches, in defiance of Costa Rican law.

Some of the "better" developments include, as part of the package, a reserve, set up, studied and certified by professional ecologists. There the landowner may see native Costa Rican wildlife and not be bothered by any pesty Costa Rican people. Encroaching desert behind, Gringoes ahead, what is a person to do but go to San José and help make a slum?

Costa Rica and Latin America will not be saved by making National Parks and forest preserves alone, important though that is. Much less will they be saved by making token reserves, from which "natives" are excluded, as part of a plan to woo investment dollars, nor by relegating the "natives" to the least fertile and most fragile lands. If the region is not to become a patchwork of ruined lands dotted with overcrowded cities and agribusiness farms, relieved only by a few sacrosanct reserves of greenery, then the various governments, the campesinos and outside aid and development workers must all look to the concept of land husbandry, in which the human need for sustenance and the ecological need for maintenance are wedded. Such a concept has not prevailed in Latin America.

How to develop this attitude? It would not hurt to open better channels of communication between ecologists and campesinos; to share what ecologists have learned with the people, starting in the grammar schools, rather than to make rules and let the people guess why. Hopefully this step can be implemented rapidly, since some traditional campesino behavior patterns must change – soon.

I have described how one tragedy was narrowly averted on the Osa Peninsula, and I could cite examples of smaller atrocities committed by campesinos in the name of rice and beans. What must be changed is the "frontier mentality", which is still very much alive in Latin America. While it is true that campesinos are often pushed off their farms by declining soil fertility or lured off with money, it is also true that many of them fancy themselves "pioneers", pushing on into the bush to homestead more land for the nation. This attitude and the slash and burn agriculture inherited from the aboriginal inhabitants of the Neotropics must die out in many countries for the simple reason that there is precious little frontier left. Pioneer days are already over in El Salvador and Uruguay, the only mainland Latin American countries whose entire land masses are settled, and will very soon be over in Costa Rica. There are presently only three large unsettled areas in Costa Rica – the high Talamancas, the Tortuguero Plain and the Osa Peninsula – and substantial parts of each are already in one sort of reserve or another.

Another job for those of us from abroad who are concerned for Latin America is the introduction of new concepts into rural life. Appropriate technologies, for example, composting and aquaculture, will have to be introduced from outside, since they are not in the Latin American tradition.

But, in addition to sharing our knowledge and skills, there must be confessions forthcoming from the overdeveloped world as well. One root of Latin America's problems is that "we" have encouraged and cajoled the campesino to sell the farm and work as a peon or move to the city. And when that doesn't work out, since we have demonstrated our preference for the concept of profit-oriented soil mining to that of nutrition-oriented soil husbandry, he has that much less compunction about homesteading a forest hillside which he may *know* will not sustain his family for long.

We have managed to tarnish seriously the concept of a small farm as something that is passed down in the family and therefore to be husbanded as carefully as possible. But it will not do to write off the campesino of today as being incapable of honoring that concept. And, while it is one of the legitimate functions of those of us who have formal education or training to pass on information and ideas to the campesino, neither will it do to lecture down to him. Rather, what is needed is dialogue and it will not be easily achieved.

Like it or not, we – Gringos – are the world's chief exporters of cultural influence, for better or for worse. As such, we are likely to be greeted in Latin America, according to the personality of the person we meet, with deferential courtesy (sometimes more than we deserve), or prejudicial hatred or, perhaps, the latter in the former's clothes. More balanced relationships come with time, especially if one comes to Latin America with questions, as well as facts and opinions, and acknowledges one's own ignorance. If, in time, a Gringo has the opportunity to show – not argue – that he or she prefers the country to the city or is more interested in a good diet and ecological stability than in economic development and plastic trinkets, and, if that statement is made without condescending to the campesino and his hard-earned transistor radio, then he or she will sometimes be surprised at the depth of concern for farm, family and future expressed by the campesino. In other words, the concept of husbandry is in trouble, but not dead, in Latin America.

I began this article with a series of depressing and confusing anecdotes of ecological destruction and lack of understanding on all sides, then proceeded by distributing the blame according to my lights. Since I have not allowed that all is already lost, it would be unfair of me to leave the reader in gloom or fury without offering some more positive anecdotes of comprehension and action by campesinos and intelligent cooperation by outsiders.

One hopeful sign emerges from the sad experience of Guanacaste. I first heard the story from Abe Pena, the former Peace Corps director in Costa Rica. He told me, with some surprise, of being lectured by a taxi driver in San José about the deforestation of Guanacaste and the consequent drought. "If they keep cutting the trees and never planting," said the driver, "the whole country will be a desert." Since then I have heard the same story, with increasing frequency, from urban and rural Costa Ricans of all classes. Five years ago, only a few ecologists would have professed such a belief. Such is the extent to which at least one sophisticated ecological concept has penetrated the Costa Rican consciousness. (My account would be incomplete if I did not admit that, in some of the rainier parts of the country, I have heard people discuss deforestation as a promising new technique for moderating the weather.)

Another hopeful story comes from Guanacaste. In the coastal village of Jacó, on the border between the Nicoya beach developments and the slightly older Guanacaste desert development, an Italian family has labored for years to develop varieties of grapes uniquely suited to that environment. No fruit enjoys greater prestige in Costa Rica than the grape, but this is the first time that high quality table or wine grapes have been grown in the country. Now the family has set to work making the new varieties available to local farmers and helping them get started. In addition to bringing a sorely needed economic boost to the area, the grape is one of the plants best suited for use in the beginning stages of restoring misused soils.

Another developer of fruit varieties, Don José Maria Arias R., who was described in the first *Journal of the New Alchemists,* continues to carry on his work. Don José Maria has won international acclaim for his fruit varieties, but of more interest in the context of this piece is his thesis, directly opposed to the drift of modern agriculture, that a Costa Rican family can live comfortably on a few acres, intensively husbanded. Certainly his own finca, which covers scarcely three acres outside Alajuela, in an area which is succumbing to urban sprawl, supports his thesis. There Don José Maria, who has steadfastly refused economic assistance throughout his long life, lives well indeed on the basis of fruit trees, gardens and goats. It takes training, patience and a special genius to accomplish what he has in selective breeding, but his fruticultural techniques, as described in his book, *Fruticultura Tropical,* can be applied by anyone with land and the will to husband it.

The NAISA farm is located near the last outpost in Costa Rica of the old-time turtle strikers – the men who stood all day at sea in a canoe with balsa decoys and a harpoon, looking to strike a "hocksbill." One of our neighbors, Casimiro Dosman, better known as "Penge", who, to our sorrow, died in August of last year, was born and raised in the area and remembered how "first time" people would harpoon a turtle to eat. Then came the days of good markets for hocksbill shell. Turtles were killed far in excess of need and the meat thrown to the dogs. The persecution was intensified with the advent of a market for turtle eggs. Where before it was customary to take part of a clutch and leave some to hatch, now every egg in most nests is harvested and sold. As a result, turtles are scarce. Penge preached on this in Spanish and Caribbean English: "God made the animal them for we to *use.* But if you wish to *sell,* you must cultivate. I see plenty people sell hocksbill shell, trunkie egg. But sha! I don't see no turtle farm." People listened. Penge's widow, Miss Ida, takes it a step further. She explains any and all hardships suffered by the turtle strikers: "God chastise them for kill too much turtle."

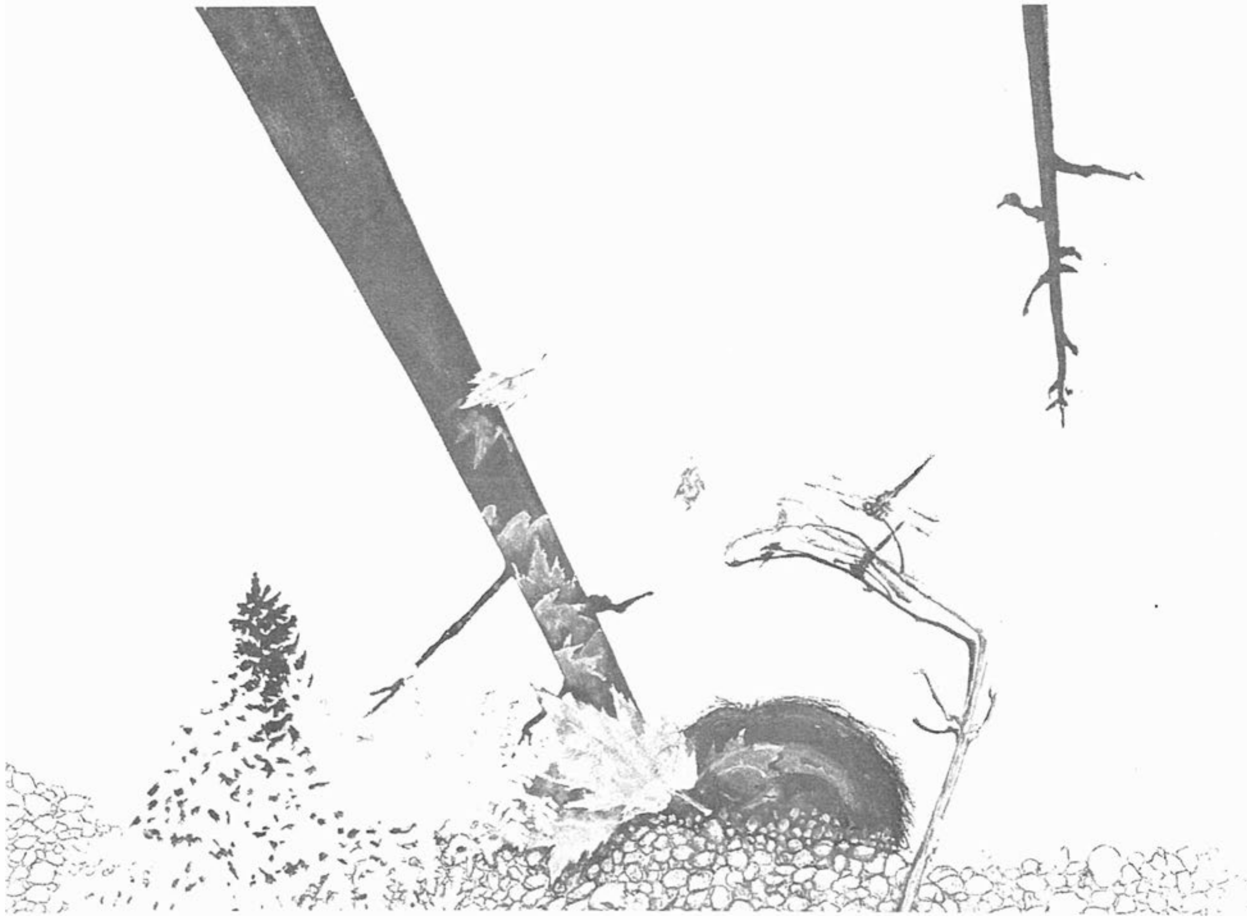
Another of our neighbors, Andres Matute, age fourteen, has been planting selected hardwood trees for four years now – so that when he is older he will have the wood to build his house. He is one of the brightest youngsters in the community, and he wants to stay there, on his father's farm. He does not want to be a "pioneer", a peon, or to live in town.

Those of you who received our 1977 calendar have already met Andres' father, Geronimo Matute, age sixty-one, born in Honduras, never spent one day in school, fought with Sandino in Nicaragua, worked for United Fruit Company in Panama, a founder of his community, president of the local Junta Directiva, and now a board member of NAISA. Matute says "La planta vale mas que la plata." (This loses something in translation – "The plant is worth more than the money.") "Porque la plata termina, pero la planta vive y cosecha y da semillas." (Because the money comes to an end, but the plant lives and bears fruit and gives seed.") If there is one person who is influential in the community, it is Matute, and I hear him haranguing community meetings about the need for reforestation – in a part of Costa Rica which cannot yet be termed deforested.

And I say there is hope yet to build a Latin America of people in harmony with nature. This will not happen without the campesino in full participation. Neither is it likely to happen with the campesino alone. We need the insights, skills and knowledge of the ecologist, the agronomist, the nutritionist and the appropriate technologist. We may possibly excuse the ruin of soils and environments in times past – say, the deforestation of ancient Greece – in that perhaps the people were ignorant of the consequences of their acts, or had no alternatives, or because the areas of land involved were relatively small. None of these excuses will serve today in Latin America.

We are favored, these days, with a great deal more knowledge of ecology, especially tropical ecology, than before. We have the whole new (for the Western Hemisphere) discipline of aquaculture, which seems particularly appropriate to most Latin American environments. We know composting and reforestation techniques. We know a great deal more about nutrition than before. We are in a better position to predict the consequences of our acts, and we have previously unequalled technology to propagandize and communicate what we know.

What is needed is to find the Penges and Miss Idas and Matutes in each community and tap their knowledge and abet their influence in their communities. What is needed is the counterparts of the Italian family in Jacó. What is needed is for interested ecologists and researchers and tecnicos in all fields to drop any preconceived notions, pick up the machete and live with and as campesinos. What is needed is for those of us with particular skills or knowledge to bring that knowledge to where it is needed – not just to some government office or university or development agency or company, but to the campesino. Even before that, we must ask the campesino what he knows, what he needs to know, what questions he and the researcher might ask together. It is this task that NAISA has set itself.



The Life of the Naturalist, Jean Henri Casimer Fabre, 1823-1915

— Meredith Fuller Luyten

Peace the love of the process of our lives.
—Muriel Rukeyser

In a word, all those vague, unconscious, rudimentary and almost nameless little lives which surround us on every side and which we contemplate with eyes that are amused, but already thinking of other things......
— Maurice Maeterlinck

There is a street in Cambridge, Massachusetts, named for the botanist who established a system of nomenclature for the natural sciences. Eight years ago, I was sitting in a library on one side of Linnaean Street, attempting to re-establish a writer's routine. On the other side of the street was an apartment where my first baby was being cared for. I was excited and anxious, unable to think wholly of the child or my work. Restive from conflicting stimulations, I turned to the stacks behind me and pulled out a book with the interesting title, *The Life Of The Spider.* I glanced at the chapters. Chapter III, "The Narbonne Lycosa", began, "The Epeira, who displays such astonishing industry to give her eggs a dwelling-house of incomparable perfection, becomes, after that, careless of her family."

Thus I first met Jean Henri Fabre, the French entomologist whom Charles Darwin called "the incomparable observer." Who was this man who wrote so compellingly of the insect and of himself that I felt I had studied by his side in the dusty fields of Provence? His style was anecdotal, discursive and his vivid descriptions of insects were often anthropomorphic. Biology flowed into philosophy without shame. Who was more attractive – the writer, the entomological teacher or the struggling paterfamilias? Fabre was a teller of stories. Instinctively, he wove the events of his life together with his scientific observations to form a cloth that was whole but distinct in detail. It did not occur to me at the time that this is a characteristic of all great naturalists.

Fabre was one of the first great behavioral scientists. Edwin Way Teale says of him, "He produced some of the basic studies of the nature of instinct. All students of insect behavior, of comparative psychology, of experimental biology are indebted to Fabre." His observations provided overwhelming evidence for the complex sequences of instinctive behavior in insects. His intuitive powers made him suspect biological mechanisms that could only be isolated a hundred years later by molecular biology. When I first heard of pheromone communication, in which chemicals secreted by an animal operate at great distances to stimulate a response in another animal, I remembered a passage from Fabre on the courtship of moths: "but what are we to say of the Great Peacock and the Banded Monk, making their way to the female..... they hasten from the ends of horizon. What do they perceive at that distance? Is it really an odor, as our physiology understands the word?...... It would be tantamount to reddening a lake with an atom of carmine, to filling immensity with nothing." This *is* an excellent analogy for the dispersion of potent pheromone molecules. Fabre's experiments convinced him that there was "an unknown sense" mechanism in operation, and he guessed accurately that the moths' antennae were the "scent" receptors.

Throughout his life, Fabre was interested in mechanisms of perception. How, he asked, do creatures know their worlds? "Inclined as we are – and it could not well be otherwise – to judge all things by our standard, the only one in any way known to us, we attribute to animals our own means of perception and do not dream that they might easily possess others...... Cannot certain properties of matter, which have no perceptible action upon us, find a receptive echo in animals, which are differently equipped?"

How do we as human beings know our world? Konrad Lorenz has made this observation about behavioral studies of animals, or the field of ethology: *"it is essential to conduct an extensive period of general observation, which must precede the performance of experiments.* He who maintains that he has no time for such observation, which is at first not directed at a particular goal, should leave animal psychology well alone." The italics are Lorenz's own.

Like Lorenz, Fabre confessed that often his most important observations were fortuitous, his best experiments accidentally conceived. He called this experience his "method of ignorance", by which he meant that observations made without prior expectation or hypothesis are particularly trustworthy in behavioral studies. Long before the advent of ethology Fabre knew that only patient field observations of long duration can establish the normative relationships of animals within their ecosystem.

Descriptive observation is still essential in many sciences. But observation, more than experiment perhaps, is inherently subjective and impossible to duplicate. Although journals of behavioral science read as if method and terminology can remove the subjective element from observation this is only an unwieldy linguistic illusion. Fabre's writing offers another response to language. He leans into the subjective life of his mind, revealing his person. He would have agreed with Lorenz's statement that observations can only be evaluated when the observers know each other and know how and what each other tends to perceive. There are styles of perception which are mirrored in styles of communication. But how *can* observers know each other? How can personality and its style become a vehicle for accurate communication?

In a recent article in *Science* magazine, called, "Hubris in Science", Lewis Thomas describes a new response to the modern problem of sheer quantity of scientific research:

"So, communication has become a serious problem not only between the scientists and the public, but among the scientists themselves. How do the investigators cope with the problem? Not, I think, by relying on computerized library services, although increasingly clever systems for retrieving more or less current information have come into existence in recent years. Nor are the journals themselves used as extensively as they used to be as sources of new information.

"What is happening is that there is much more reliance on word of mouth for the transmission of scientific data than ever before in my memory..... There is a new system at work, which I do not understand. I have the impression that a great body of information is getting around by a mechanism that can only be termed gossip."

Thomas is talking about the telephone, but he is also talking about the rediscovery of person-to-person "gossip", and the odd reliability which dealing directly with the person of the investigator seems to have for us.

Were the discursive, autobiographical, anecdotal and anthropomorphic elements of Fabre's writing naive and outdated as techniques for scientific writers of today? Could it be that, on the contrary, these are essential characteristics of his contribution to science? A look at Fabre's life and writing might provide an answer to these questions.

Beginning an autobiographical essay, Fabre said, "Since Darwin bestowed upon me the title of 'incomparable observer', the epithet has often come back to me, from this side and from that, without my yet understanding what particular merit I have shown. It seems to me so natural, so much within everybody's scope, so absorbing to interest one's self in everything that swarms around us! However, let us pass on and admit that the compliment is not unfounded.

"My hesitation ceases if it is a question of admitting my curiosity in matters that concern the insect.... yes, I confess that I am an enthusiastic observer of the animal. How was this characteristic propensity, at once the torment and delight of my life, developed?"

J. Henri Fabre was born on December 22, 1823, in the village of Saint-Léons in Provence. He remembered his parents as stern and harassed people, but not as unkind ones. They were so poor that they sent the young child, known as Henri, to live with his paternal grandparents, on their farm near Malaval. In Fabre's words, "They were people of the soil, whose quarrel with the alphabet was so great that they had never opened a book in their lives; and they kept a lean farm on the cold granite ridge of the Rouerge table-land. The house, standing alone among the heath and broom, with no neighbour for many a mile around and visited at intervals by wolves, was to them the hub of the universe...... In this wild solitude, the mossy fens, with their quagmires oozing with iridescent pools, supplied the cows, the principal source of wealth, with rich, wet grass. In summer, on the short swards of the slopes, the sheep were penned day and night, protected from beasts of prey by a fence of hurdles propped up with pitchforks.... In the centre was the shepherd's rolling hut, a straw cabin. Two watch-dogs, equipped with spiked collars, were answerable for the tranquillity if the thieving wolf appeared in the night from out the neighbouring woods.

"Padded with a perpetual layer of cow-dung, in which I sank to my knees, broken up with shimmering puddles of dark-brown liquid manure, the farm-yard also boasted a numerous population. Here the lambs skipped, the geese trumpeted, the fowls scratched the ground and the sow grunted with her swarm of little pigs hanging to her dugs."

This is the setting of Fabre's earliest memories. He identified with these grandparents, especially his grandmother, more than with his own parents. He remembered his grandmother's warmth, her abundant meals, good humor and her capable strength as a farmer's wife. She was of a practical temperament, but, to the small intense domain of the farmyard, she added her gifts as a story-teller. Her stories were often of wolves, as heroic and fantastic as dragons. "I should very much have liked to see this wolf," Fabre wrote, "but the shepherd always refused to take me into his straw hut, in the middle of the fold, at night." Added to Fabre's sharp observations of real animals were the exploits of fantastic animals. His first books were to be an ABC bestiary and La Fontaine's *Fables.*

Often alone, the young Henri had time for reflection and observation. He soon learned that his curiosity about animals was met with amusement or impatience, because it went beyond the practical needs of his grandparents as farmers. Early in his childhood, natural history became a pleasure which Fabre's secrecy protected from ridicule. He had to put his questions directly to his animals. He began to search and experiment and he gives us this extraordinary account of one of his earliest memories – a test of perception:

"I was five or six years old..... I can see myself plainly, clad in a soiled frieze frock flapping against my bare heels; I remember the handkerchief hanging from my waist by a bit of string.....

"There I stand one day, a pensive urchin, with my hands behind my back and my face turned to the sun. The dazzling splendour fascinates me. I am the Moth attracted by the light of the lamp. With what am I enjoying the glorious radiance: with my mouth or my eyes? That is the question put by my budding scientific curiosity.... I open my mouth wide and close my eyes: the glory disappears. I open my eyes and shut my mouth: the glory reappears. I repeat the performance, with the same result. The question's solved: I have learnt by deduction that I see the sun with my eyes. Oh, what a discovery! That evening I told the whole house all about it. Grandmother smiled fondly at my simplicity; the others laughed at it."

In childhood, Fabre's only teachers of natural history were other children. Inherited superstitions coupled or clashed with his private observations and stimulated his curiosity further. Children, not adults, valued gratuitous bits of information – such as methods for hypnotizing a goose, where to find bird eggs, or that the grasshopper's hind leg has a "pleasant shrimpy flavor."

When Fabre was eight years old, he was returned to his parents. To help the family income he was given the job of raising a flock of ducklings. He herded them down the stoney paths of the village, beyond the houses, to a pond where they could find food. Here he spent hours exploring the shores of the pond. He found gold-dust, diamonds and a tiny rams horn turned to stone. Coming home with bulging pockets, he was scolded for ruining his clothes and was told to throw his treasures away. Was it fortunate or regrettable that there was no one to tell him that what he really had found was mica, rock crystals and a fossilized snail, common to that area? As with most children, Fabre's fantasies only whetted his appetite for more experience of the actual world. This paradox would one day enrich his writings as a naturalist.

As an old man, Fabre remembered this pond of his childhood and a succession of ponds connecting a child's and a scientist's sense of wonder:

"I will return to the pond, but not that of the small ducks, a pond aflower with illusions. Those ponds do not occur twice in a lifetime. For luck like that, you must be in all the new glory of your first breeches and your first ideas.

"Many another have I come upon since that distant time, ponds very much richer and, moreover, explored with the ripened eye of experience. Enthusiastically I searched them with the net, stirred up their mud, ransacked their trailing weeds. None in my memories comes up to the first, magnified in its delights and mortifications by the marvellous perspective of the years.

"Nor would any of them suit my plans of today. Their world is too vast. I should lose myself in their immensities, where life swarms freely in the sun. Like the ocean, they are infinite in their fruitfulness..... What I want is a pond on an extremely reduced scale, sparingly stocked in my own fashion, an artificial pond standing permanently on my study table."

This is more than a prologue to experimentation. These ponds become a metaphor for changing perception. As the observer becomes more skilled, the world becomes more complex. The pond of this passage *is* the evolving human eye.

Until adolescence, when Fabre assumed responsibility for his own education, his formal schooling was haphazard. From the age of seven to ten, he studied in his godfather's village school, which was also his godfather's bedroom and kitchen. The room was warm only because a fire was maintained to cook the pigs' mash. Piglets and chickens wandered in and out. His godfather was benignly inattentive. Study was readily interrupted so that the dovecots could be cleaned or snails crushed by the children in the estate gardens. For Fabre's grandfather "managed the property of an absentee landowner..... He had under his care an old castle with four towers", and he also worked as the village barber, bell-ringer, choir-singer and the winder of the village clock. "This was his proudest function," Fabre writes. "Giving a glance at the sun, to ascertain the time more or less nearly, he would climb to the top of the steeple, open a huge cage of rafters and find himself in a maze of wheels and springs whereof the secret was known to him alone." This picture suggests the medieval quality of Saint-Léons in Fabre's childhood, a town in which the small rounds of life were as self-contained and unquestioned as the inner workings of his grandfather's clock.

Fabre's family moved to the larger town of Rodez. His education here was erratic, interrupted by the financial needs of his family. Eventually he won a scholarship at the École Normale Primaire in Avignon. Fabre trained to become a teacher, concentrating on math and physics. He could foresee no post as a teacher of natural science, and he relegated his natural history books "to the bottom of a trunk." But during his adolescence Fabre gained confidence in his ability to teach himself and to learn by teaching others. When a chemistry lesson ended in a disastrous explosion, Fabre was stimulated to repeat the experiment correctly a year later. He remarked with good humor that teaching is, after all, only "the fulminate awakening the slumbering explosives."

Fabre acquired a teaching position in Corsica. Here at last he met two naturalists who could encourage his study of plants and insects. Moquin-Tandon especially encouraged Fabre to study the living animal, and he restored Fabre's ambition to pursue a career as a teacher of natural history.

In 1852 Fabre became a teacher at the lycée of Avignon. He meanwhile was laying his plans toward a university professorship, not knowing that he would hold this teaching position at the lycée for eighteen years. He prepared his thesis for "doctorat es sciences naturelles," which he defended in Paris. In 1854 he was galvanized by his discovery of the entomological work of Léon Dufour. Dufour was publishing behavioral observations of insects and Fabre realized that he himself was capable of making a contribution to Dufour's work on wasps. He began to publish his findings and in 1856 he received an award from the Institut de France for his work in experimental physiology. By now Fabre had a large family. He was never free from financial worry. Although he had attracted the attention of such famous men as Darwin and Pasteur, he was unable to accept a position on the faculty of Poitier University simply because he lacked the necessary private income. This was a bitter lesson in the inequities of an educational system. How was he to work and still have the time for his entomological studies? For a while, he turned all his attention to gaining economic independence. After much work, he developed a cheap method for the production of madder dye, a dye which was very important to the textile industry of his region. He received an award from Napoleon III for this work, but then the development of artificial alizarin destroyed his dye's market.

In yet another area, success was to be followed by mishap and thwarted ambition. Fabre's gifts as a teacher had long been recognized by Victor Duruy, Napoleon's enlightened minister of education. During official tours of the provinces, Duruy had encouraged Fabre to enlarge his goals and offer his liberal ideas in education to the community of Avignon. In the 1860's, Fabre gave free public lectures in natural history at the old Abbey of Saint Martial, the abbey in which he had long ago witnessed the disastrous explosion of chemicals in a badly managed experiment. In the Abbey of Saint Martial, he at last had a forum for his ideas and, perhaps, a broader forum than a university professorship could have given him. His lectures provided an open university system, free to all. He was making education available to any age and economic background; he was providing secondary education for girls; he was giving natural history a central place in the curriculum of country school children. Fabre attracted large audiences and, in so doing, he also caused alarm in this provincial town. He made enemies, particularly among the clergy. In 1870, he lost his job at the lycée and at the same time he was evicted from his house, for which he held no lease. John Stuart Mill, who then resided in Avignon, gave Fabre generous financial help that enabled him to establish a new household in Orange.

Fabre seemed to have lost his teaching career, but instead he now began a new, more important stage of it. He turned to the writing of popular scientific books as a means of support. Some of these books, which Fabre made more acceptable to clerics through the inclusion of frequent pious sentiments, became texts for school children. Others were intended to provide adult education to farming communities, offering principles of household hygiene and practical information on animal husbandry and the life-cycles of pesty and helpful insects. Through this period of prodigious writing, Fabre gained the experience as a stylist which he brought to his later volumes of entomology. He continued his work in the fields with insects, but he felt increasingly harassed by his dependency on public byways and lands that were not his own. It became his ambition to acquire a piece of land where his experiments and observations would be undisturbed by passers-by.

In 1879 Fabre had enough royalties from his books to purchase a little less than three acres of land in Sérignan, Provence. Poor, untilled land, suitable only for occasional grazing, such a piece was known as a *harmas*. On this *harmas* there was a house, a small pond, and dry, thistly fields abounding with insects.

Fabre reached his *harmas* in a state of exhaustion and grief. His promising son and working companion, Jules, had just died at the age of fifteen. Fabre himself had almost died in a bout with pneumonia. He had four young children and an aged father to care for. Shortly after the move, his wife, Marie, died. Fierce pride had carried him through misfortunes and lonely struggles to this hard-bitten piece of land. He recognized his own life in the solitude of the *harmas*. In an impassioned essay of that title, he defended his life's choices and his purpose in taking refuge on this bit of land:

"Come here, one and all of you – you, the sting-bearers, and you, the wing-cased armour-clads – take up my defence and bear witness in my favour. Tell of the intimate terms on which I live with you, of the patience with which I observe you, of the care with which I record your actions. Your evidence is unanimous: yes, my pages, though they bristle not with hollow formulas nor learned smatterings, are the exact narrative of facts observed..... and whoso cares to question you in his turn will obtain the same replies.

"And, then, my dear insects, if you cannot convince those good people, because you do not carry the weight of tedium, I, in my turn, will say to them:

'You rip up the animal and I study it alive; you turn it into an object of horror and pity, whereas I cause it to be loved...... natural history, youth's glorious study, has, by dint of cellular improvements, become a hateful and repulsive thing. Well, if I write for men of learning, for philosophers, who, one day, will try to some extent to unravel the tough problem of instinct, I write also, I write above all things for the young.'

"When shall we have an entomological laboratory for the study not of the dead insect, steeped in alcohol, but of the living insect; a laboratory having for its object the instinct, the habits, the manner of living, the work, the struggles, the propagation of that little world, with which agriculture and philosophy have most seriously to reckon?..... While waiting for the fashion to change, I open my *harmas* laboratory of living entomology; and this laboratory shall not cost the ratepayers one farthing."

Though Fabre became known as "the hermit of Sérignan", this picture of him must be balanced by recollections of Fabre's friends and passages of Fabre's own reminiscences which reveal a personality of considerable charm and warmth.

Fabre was a devoted father and husband. He married a second time and eventually had seven children. His desire to improve the quality of education for girls arose naturally from the equality with which he treated his children, most of whom were daughters. His collector's walks were also spirited family outings. His wife and children often shared his excitement or patience in making a new observation in the fields. Or late at night they would rush to his laboratory, summoned by his elation with a new discovery. One biographer and friend said, "It was not with Fabre as with some intellectuals, whose thoughts and life remain almost strangers to the home which they establish one day as though in a moment of distraction, and who divide their lives into two parts."

Fabre made innumerable farmers and their wives, village urchins, servants and shopkeepers into enthusiastic as well as invaluable collectors of cocoons and insects for his laboratory. The pleasure which he found in his work was infectious and still is infectious to us today as we find it in his writing. On one occasion, Fabre invited his family and friends to join him in testing the edibility of the oak caterpillar. He had read in Pliny that these were considered by the Romans to be a delicacy. With characteristic wit, he set the experiment for a Shrove Tuesday meal, since Shrove Tuesday is a "reminiscence of the ancient Saturnalia" of the Romans. He gives us the following portrait of his guests:

> "One of these is the schoolmaster. Since he permits it and does not fear the comments of the foolish, if by chance the secret of our feast should be divulged, we will call him by his name, Julian. A man of broad views and reared upon science, his mind is open to truth of every kind.
>
> "The second, Marius Guigne, is a blind man who, a carpenter by profession, handles his plane and saw in the blackest darkness with the same sureness of hand as that of a skillful sighted person in broad daylight. He lost his sight in his youth, after he had known the joys of light and the wonders of colour. As a compensation for perpetual darkness he has acquired a gentle philosophy, always smiling; and ardent desire to fill, as far as possible, the gaps in his meagre primary education; a sensitiveness of hearing able to seize the subtle delicacies of music; and a fineness of touch most extraordinary in fingers calloused by the labours of the workshop. During our conversations, if he wishes to be informed as to this or that geometrical property, he holds out his widely-opened hand. This is our blackboard. With the tip of my forefinger, I trace on it the figure to be constructed; accompanying my light touches with a brief explanation. This is enough; the idea is grasped, and the saw, plane and lathe will translate it into reality.
>
> "On Sunday afternoons, in winter especially, when three logs flaming on the hearth form a delicious contrast to the brutalities of the Mistral, they meet in my house. The three of us form the village Athenaeum, the Rural Institute, where we speak of everything........"

In this description of Marius, the blind carpenter, I am again struck by Fabre's interest in matters of perception. With people as well as with insects, as a teacher and as a behavioralist, he always asks himself how a being with endowments different from his own experiences the world. What common ground, he wonders, might we have? In recording his own investigations, he frequently uses imagery that evokes the world of the blind, a world of darkness in which he gropes and moves forward hesitantly; and a world in which each creature's domain is finally private:

> "I sally forth in the night, with a lantern, to spy out the land. Around me, a circle of faint light enables me to recognize the broad masses fairly well, but leaves the fine details unperceived. At a few paces' distance, the modest illumination disperses, dies away. Farther off still, everything is pitch-dark. The lantern shows me — and but very indistinctly — just one of the innumerable pieces that compose the mosaic of the ground.....
>
> "The domain of this Weevil is.... a slender thistle, not devoid of elegance, harsh-looking though it be. Its heads, with their tough, yellow-varnished spokes, expand into a fleshy mass, a genuine heart, like an artichoke's, which is defended by a hedge of savage folioles broadly welded at the base. It is at the centre of this palatable heart that the larva is established, always singly.
>
> "Each has its exclusive demesne, its inviolable ration......."

The vivid strength of such a passage evokes Fabre's own lifetime identification with the solitary struggles of common people, the strong weeds who "have no history," but whose individual efforts contain great drama nevertheless. Again and again, in the teeming instinctual world of insects, he creates vivid portraits of individual effort. And these portraits derive energy from and lend support to the struggles of his own life.

Between 1879 and 1910, the ten volumes of Fabre's *Souvenirs Entomologiques* were published. They did not attract great attention. Then in the last five years of his life Fabre was officially discovered. The French government and scientific institutions of France and other countries honored him with a jubilee in Sérignan, in 1910. He received Stockholm's Linnaean Medal and he was nominated for the Nobel Prize. But Fabre found this fame that came so late to be exhausting and ironic. When his eyesight was failing, he was deluged with expensive microscope and laboratory equipment which he had never had the benefit of before. Again he was to find himself surprised and bemused by differences of perception. Shortly before his death in 1915, he learned that a statue of himself was to be erected in his village.

He said to a friend, "I shall see myself, but shall I recognize myself? I've had so little time for looking at myself!"

A friend and biographer of Fabre gives this description of the aged naturalist, confined by old age to his chair and almost totally blind:

"To see him in the twilight of his diningroom where he silently finished his life, majestically leaning back in his arm-chair, with his best shirt and old-fashioned necktie, his eyes still bright in his emaciated face, his lips fine and still mobile, but thin with age and at moments trembling with emotion, or moved by a sudden inspiration – to see him thus, would you not say that he was still observing?"

Fabre may not have had much time for looking at himself, but in his writing he gave us his life as a vehicle with which we join him in observation of the world. He made his life into an epic journey, emblematic of the life journeys of all creatures. Maeterlinck called Fabre the Homer of insects, a poet of science. The opening lines of *The Odyssey* could serve as an invocation for Fabre's own epic, the *Souvenirs.* It might indeed be an invocation from all of Fabre's personable insects:

Sing in me, Muse, and through me tell the story
of that man skilled in all ways of contending,
the wanderer, harried for years on end.......

* * * * * * * * * *

If there is a persistent quality to be found in Fabre's work it is the quality of empathy. Empathy is much more of a discipline than that related emotion, sympathy. Empathy enables a person to identify with another life without confusion, without ceasing to respect the separateness of lives. It is a response very similar to generous love. If this sounds a bit far from the pragmatic routines of a student of animal behavior, consider the following words of Konrad Lorenz from his book, *Studies in Animal and Human Behavior:*

"Ethology is the *comparative* study of behavior..... [to become an expert in this field] it is necessary to become thoroughly familiar with a group of related animal species. Such familiarity is not easily achieved. In fact, it seems necessary to become emotionally involved to the point of 'falling in love' with such a group in the way many bird-lovers and.... other kinds of 'amateurs' do. Without this emotional motivation, no thorough knowledge of the comparable behavioral traits of any group of animals could ever be gained. Were it not for the unaccountable gloating pleasure some of us take in watching 'our' animals, not even a person endowed with the supernatural patience of a yogi could bring himself to stare at a fish, a bird or an ape with the unremitting perseverance which is necessary in order to perceive the governing principles prevailing in the behavior of an animal."

Fabre was a great writer and naturalist because he had what one biographer called "the gift of correspondence." A truly great naturalist brings some aspect of nature into sharper focus *not by isolating it but by clarifying its relationships,* its place in nature. This is really an unromantic view of naturalists, because it makes their function that of go-betweens. Like a translator or a diplomat, a naturalist can reduce the barriers between intelligent systems of life that speak somewhat different languages.

Niko Tinbergen, in arguing for the eventual partnership of psychology and biology, wrote in 1951, "introspection brings us into contact with an aspect of behaviour that is out of reach of objective study. We know that both aspects belong to one reality, but somehow the scientist's mind is unable to synthesize them into one harmonious picture." Fabre's writing intuitively conveys this harmony. And in the 1970's we have more scientific evidence, which may simply mean more scientific willingness, with which to understand this harmony.

Lewis Thomas and Edwin Land are two scientists of different disciplines who recently have written about the partnership of inner and outer orders which forms human experience. As a medical researcher, Lewis Thomas provides us with a new paradigm for understanding disease. Disease has been understood as the invasion of an organism by another foreign organism. It might better be understood as a biological misunderstanding or misinterpretation of boundaries between organisms that *can* understand or misunderstand one another only because they have a long evolutionary association. To even *see* one another, let alone interact with one another, different organisms must share some order or language.

Research into mechanisms of visual perception has enabled Edwin Land of the Polaroid Corporation to draw a related conclusion about the interaction of the human eye and the 'outer world' it sees. Land's research provides a synthesis for our ideas of subjective and objective perception that Tinbergen hoped for. And since his study of the eye illuminates the complimentary skills of observation and communication that a good naturalist possesses, I will let Land speak for himself. Compare his reminiscence from childhood with Fabre's childhood experiment with perception:

"In my hometown library, the chief delight of the younger patrons was not the books but the Brewster stereoscope. Through its lenses, children saw boats and bridges and canals and mountains, and the best of all three-dimensional subjects, grottoes. The stereoscope transport-

ed the child through the interplay of stalagmites and stalactites into the distant depths of the caves, having converted two slightly faded sepia, flat, dull photographs into a vivid reality. You could hear the dripping water, smell the dampness, fear the darkness as you sat with your legs crossed under you..... *Where did this new reality exist?* In your eyes, or rather did you exist in it? A toy? Or the most powerful metaphysical clue to emerge in three thousand years? ....
the child and the three-dimensional space he rejoiced in seeing comprised one single union of mind and matter..... In this particular pre-Darwinian period [when the stereoscope was invented] , no one could have had the courage to imagine what, in the next two hundred years, would become the scientific basis of an unpartitioned reality."

We have evolved, Land says, "in a polar partnership with the world." He continues:

"there really is no outside world and no inside world. There is just one world. It is, perhaps, a little bit like moss growing on a rock, clinging to it, the tendrils penetrating the crevices in the rock and the cavities of the rock, where the rock/moss combination is the object and not the rock or the moss separately."

It is, then, as Fabre said, "so much within everyone's scope" to be observers of the world. Perception is an act of unification available to us all every time we open our eyes. A naturalist is exceptional in raising this endowment to an art, to an act of celebration.

The interests of a naturalist are usually understood by their own time to be interdisciplinary, unifying separate fields of study. In its own time, Fabre's behavioral approach to the insect was a radical integration of psychology and morphology. Great naturalists provide data for the "unpartitioned reality" of nature. But few scientists would consider a narrative style to be an integral part of scientific contribution. Fabre's writing is not just a 'means' of conveying data. It is itself data, and some of the very best data, for the unity of mind and nature.

It is not fortuitous that Lorenz, Tinbergen, Thomas and Land are all good writers. Between people, between species, between our minds and the world around us there can be a rigid or a supple interface. Our language can emphasize isolation or relationship. In general, the best naturalists are also specialists in some scientific field. However, they are specialists who have the ability as writers or artists to overcome the alien associations of inaccessibility and loneliness which the word specialist has come to have. A good scientist has entered strange and possibly frightening territory. A good writer provides us with the necessary empathy, the necessary relationship, to follow on that journey. A good writer sustains our participation in his or her world. When Land begins an article with a childhood reminiscence he is giving us a way in. And when he begins to talk about rock and moss he is turning to a writer's most powerful tool: metaphoric language.

Metaphoric language is one of the ultimate human expressions of trust in the unpartitioned reality of mind and matter. Metaphor is "language that implies a relationship." An ordinary metaphor is merely illustrative, but a great metaphor is organic and forms "a fresh relationship." The formation of metaphor in the human mind is analogous to the increasing complexity of an ecosystem in nature: definitions of lives arise more and more from their relationships. The filling of specific ecological 'niches' also might be compared to the development of more precise language with which to express our commonality.

Journals of science reveal a fear and distrust of the richness of language. Language is indeed hazardous. Words with the briefest of histories are subject to alchemical transformations, mutations and emotional colorations. Language seems to insist on its right to cross-pollination if it is to remain fertile. It has a life of its own. Yet it is the tendency of scientific writing to coin new technical words and attempt to fix the usage of old ones, for ambiguity is felt to be a disability in sharing scientific investigations. Consistent usage and rigid definition are shibboleths to protect against misreading. Of course, this fixity of language has genuine uses. Essentially it replaces what Lorenz pointed out to be the necessary first-hand relationship between observers that makes them able to understand each other's findings. It is interesting to note how the usefulness of a fixed vocabulary is analogous to the usefulness of instinctive behavior: It requires no imaginative interpretation, but it is easily made obsolescent by a change of environment. The paranoia of many behavioral scientists about verbal ambiguity seems to be a self-defeating tendency, and certainly a quixotic one. Lovers of language value its hazardous nuances and would no more discard a word's layers of association than an antique dealer would scrub the patina off an old brass pot. The treacherous fluidity of language ultimately cannot be avoided by a scientist any more than it can by a poet. It offers a precision in communication which is of a different order. Metaphor is a precise and subtle tool for describing reality.

Fabre once said that "in the world of creatures, as in the world of men, the story precedes and outlives history." He developed the ability of a fabulist to make an animal expressive and to turn the behavior of animals into narrative. But he realized that for fabulists such as Aesop and LaFontaine the animal was "little more than a pretext for comparisons and moral narratives." It became merely illustrative of human foibles. This is unabashed anthropomorphism in its most manipulative form. But consider this passage in which Fabre describes the encounter of a Praying Mantis and a hunting wasp, or Sphex, returning to her burrow with a paralyzed grasshopper:

"When entering her shelter under the rock, where she has made her burrow, the Sphex finds, perched on a blade of grass, a Praying Mantis, a carnivorous insect which hides cannibal habits under a pious appearance. The danger threatened by this robber ambushed on her path must be known to the Sphex, for she lets go her game and pluckily rushes upon the Mantis, to inflict some heavy blows and dislodge her, or at all events frighten her and inspire her with respect. The robber does not move, but closes her lethal machinery, the two terrible saws of the arm and fore-arm. The Sphex goes back to her capture, harnesses herself to the antennae and boldly passes under the blade of grass whereon the other sits perched. By the direction of her head we can see that she is on guard and that she holds the enemy rooted, motionless, under the menace of her eyes. Her courage meets with the reward which it deserves: the prey is stored away without further mishap.

"A word more on the Praying Mantis, or, as they say in Provence, *lou Prégo Dieóu,* the Pray-to-God. Her long, pale-green wings, like spreading veils, her head raised heavenwards, her folded arms, crossed upon her breast, are in fact a sort of travesty of a nun in ecstasy. And yet she is a ferocious creature, loving carnage. Though not her favourite spots, the work-yards of the various Digger-wasps receive her visits pretty frequently. Posted near the burrows, on some bramble or other, she waits for chance to bring within her reach some of the arrivals, forming a double capture for her, as she seizes both the huntress and her prey. Her patience is long put to the test: the Wasp suspects something and is on her guard; still, from time to time, a rash one gets caught. With a sudden rustle of wings half-unfurled as by the violent release of a clutch, the Mantis terrifies the newcomer, who hesitates for a moment, in her fright. Then, with the sharpness of a spring, the toothed fore-arm folds back on the toothed upper arm; and the insect is caught between the blades of the double saw. It is as though the jaws of a Wolf-trap were closing on the animal that had nibbled at its bait. Thereupon without unloosing the cruel machine, the Mantis gnaws her victim by small mouthfuls. Such are the ecstacies, the prayers, the mystic meditations of the *Prégo Dieóu.*"

Fabre is not crediting the Mantis with the human faculty of hypocrisy; nor is the Mantis a vehicle for anticlerical diatribe. Fabre is using a wide number of common associations to stimulate our perception of this moment, and to form a relationship between the insects and ourselves. The words "robber", "lethal machinery", "enemy", "reward", "nun", "patience", and the marvelous use of "clutch" and "Wolf-trap" do not make this scene a human drama, but they do make it comprehensible to us through our dramatic faculties as human beings. This is an important distinction. Fabre is not making value judgments that *deflect* attention from the insects; he is establishing some correspondence in order to focus our attention and empathy. Rather than being naive, he is deftly prodding us when he asks, "Why is the Sisyphus Beetle a hard-working paterfamilias and the Sacred Beetle an idle vagabond?" Wit, not morality, defines his narratives.

For communication to occur between species, an innate distrust of the strange must be overcome. For us this is particularly true in the case of insects. Fabre makes sophisticated use of the close relationship between fear and fascination, repulsion and attraction, to arrive at our underlying identification with insects. His fluid use of language expresses a courageous, vigorous encounter with the strange:

"To emerge from underground after the perfect insect is hatched, the Bluebottle's device consists in disjointing her head into two movable halves, which, each distended with its great red eye, by turns separate and reunite. In the intervening space, a large, glassy hernia rises and disappears, disappears and rises. When the two move asunder, with one eye forced back to the right, the other to the left, it is as though the insect were splitting its brain-pan in order to expel the contents. Then the hernia rises, blunt at the end and swollen into a great knob. Next, the forehead closes and the hernia retreats, leaving visible only a kind of shapeless muzzle. In short, a frontal pouch, with deep pulsations momentarily renewed, becomes the instrument of deliverance, the pestle wherewith the newly-hatched Bluebottle bruises the sand and causes it to crumble."

Fabre has magnified the scale of the insect so that we can feel the power and precision of the fly's minute head and experience its emergence as a herculean effort. It is this image of effort, as well as the sexual quality of the description, in human terms, that holds us. Fabre stimulates feelings in us, rather than crediting the insect with these feelings. He is giving us the necessary interest for close attention. If this is trickery it is sublime trickery. Who is receiving Fabre's attention and lavish description? Ourselves or the insect? As a scientist, Fabre had the intuition to see this as one and the same process. It is essential for an observer to risk identification, and his language tells us that.

Empathy, true knowledge, requires the participation of all levels of our minds. Fabre is bold enough to engage the power of the unconscious, which expresses itself through imagery. His imagery strikes the mind with the force that only archetypal imagery can have. Rational and irrational elements join in Fabre's most inspired descriptions. This is particularly fascinating in a writer who is a student of instinctive behavior. Because a compelling image in the human mind is analogous to the power of instinct in its ability to trigger a response. This relationship between imagery and the conscious mind has been explored by Jungians, and particularly by Erich Neumann. It is succinctly stated in the following passage by him:

> "The function of the image symbol in the psyche is always to produce a compelling effect on consciousness. Thus, for example, a psychic image whose purpose it is to attract the attention of consciousness, in order, let us say, to provoke flight, must be so striking that it cannot possibly fail to make an impression. The archetypal image symbol corresponds, then, in its expressiveness, significance, energetic charge, and numinosity, to the original importance of instinct for man's existence."

Before retiring to bed one night, Fabre put a newly-hatched female Noctuid moth under a screen bell-jar. In the light of Neumann's words, consider the charged mystery in Fabre's description of the events which ensued:

> "It was a memorable night! I will name it the Night of the Great Peacock. Who does not know this superb moth, the largest of all our European butterflies, with its livery of chestnut velvet and its collar of white fur? The greys and browns of the wings are crossed by a paler zig-zag, and bordered with smokey white; and in the centre of each wing is a round spot, a great eye with a black pupil and variegated iris, resolving into concentric arcs of black, white, chestnut and purplish red.....
>
> "I was richly rewarded. About nine o'clock that evening, when the household was going to bed, there was a sudden hubbub in the room next to mine. Little Paul, half undressed, was rushing to and fro, running, jumping, stamping, and overturning the chairs as if possessed. I heard him call me. "Come quick!" he shrieked; "come and see these butterflies! Big as birds! The room's full of them!"
>
> "I ran. There was that which justified the child's enthusiasm and his hardly hyperbolical exclamation. It was an invasion of giant butterflies; an invasion hitherto unexampled in our house......
>
> "Candle in hand, we entered the room. What we saw is unforgettable. With a soft *flic-flac* the great night-moths were flying around the wire-gauze cover, alighting, taking flight, returning, mounting to the ceiling, redescending. They rushed at the candle and extinguished it with a flap of the wing; they fluttered on our shoulders, clung to our clothing, grazed our faces. My study had become a cave of the necromancer, the darkness alive with creatures of the night! Little Paul, to reassure himself, held my hand much tighter than usual."

In this passage, Fabre has interwoven the sexual excitement of the arriving male moths and the excitement of Fabre's son, Paul, so that the evening becomes the combined discovery of insect, child, and ourselves.

Frequently Fabre's essays open with this quality of urgency or immediacy. We are invited to join him on some epic journey and we are quickly introduced to the protagonists of the adventure:

> "The month of March comes to an end; and the departure of the youngsters begins, in glorious weather, during the hottest hours of the morning. Laden with her swarming burden, the mother Lycosa is outside her burrow, squatting on the parapet at the entrance."
> (from *The Narbonne Lycosa: The Climbing Instinct)*

or to take another passage:

> "It happened like this. There were five or six of us: myself, the oldest, officially their master but even more their friend and comrade; they, lads with warm hearts and joyous imaginations, overflowing with that youthful vitality which makes us so enthusiastic and so eager for knowledge. We started off one morning down a path fringed with elder and hawthorn, whose clustering blossoms were already a paradise for the Rosechafer ecstatically drinking in their bitter perfumes. We talked as we went. We were going to see whether the Sacred Beetle had yet made his appearance in the sandy plateau of Les Angles, whether he was rolling that pellet of dung in which ancient Egypt beheld an image of the world."

Fabre has a strong element of play and pleasure in his observations which suggests a trustful awareness of the world. His style has a feminine sensuality, diffuse as well as specific, always fertile in associations, bountiful in details. It is exciting for us today, on a new wave of feminism, to see that the traditionally feminine strengths are essential to a good naturalist: a receptive and inclusive eye, an intuitive perception of relationships between living things, an ability to conserve and use all experience. And Fabre's writing about the insect world constantly evokes the age-old mythic polarities of nature: the nurturing mother and the devouring mother.

Whether he is uncovering the dark or the luminous aspects of nature, he speaks in the voice of the psalmist, inviting and celebratory. He says of a young shepherd who has led him to the nest of Scarab Beetle, "he laughed in response to my smile and was happy in my gladness." Fabre says to us, across a hundred years, "Pass the tip of your finger over the Moth's head. You will feel a few very rough wrinkles," and we do feel those wrinkles; like the carpenter, Marius, who was Fabre's friend, we touch the moth blindly but sensitively.

When we are reading about Fabre's insects, we are entering the connective tissue of the naturalist's life, a very human life, in which the harsh exigencies of conflicting roles and conflicting stimulations are conserved and made workable. Human and insect lives have their myriad characters, playing different ecological roles that jostle and define one another. Living things translate each other. The paradox of Fabre's anthropomorphism is, as he says, that "no one can sound an existence outside his own." So he gives us his whole experience as an intelligible vehicle for the journey he wishes us to make. We are sustained by the design of his perceptions, which is the natural design of his life. We read him and for a while we ourselves become incomparable observers. Maybe we even can carry a little of his gift with us into our own time, our own science. His language is a reminder that scientific models are based on analogies, and those analogies are always human.

I celebrate myself, and sing myself,
And what I assume you shall assume.
For every atom belonging to me as good belongs to you.

—*Walt Whitman*

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the light is still
At the still point of the turning world.

–T. S. Eliot
Four Quartets

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