

## Guest Editorial

### THE MANZANAR PROJECT: TOWARDS A SOLUTION TO POVERTY, HUNGER, ENVIRONMENTAL POLLUTION, AND GLOBAL WARMING THROUGH SEA WATER AQUACULTURE AND SILVICULTURE IN DESERTS

GORDON H. SATO,<sup>1</sup> TEFOM GHEZAE, AND SAMUEL NEGASSI

*Ministry of Fisheries, State of Eritrea, Box 923, Asmara, Eritrea*

(Received 20 February 1998)

#### SUMMARY

Dr. Gordon Sato is a former Editor-in-Chief of In Vitro Cellular and Developmental Biology, President of the Tissue Culture Association (now Society for In Vitro Biology), and Director of the W. Alton Jones Cell Science Center (now Adirondack Biomedical Center). He began pilot experiments on the Manzanar Project at test sites in the Salton Sea while a Professor of Biology at the University of California, San Diego and continued the project in the laboratory at the Cell Center in Lake Placid, NY and at Eritrean test sites during their war of independence. Since 1994, he spends up to 10 mo. per yr in Eritrea where he directs the Manzanar Project and trains young Eritrean scientists in the field in the area of what he refers to as “low-tech biotech.” The name of the Manzanar Project was inspired by the camp in California where Dr. Sato and his family were interned during World War II.—*The Editor*

In recent memory, famine and poverty have plagued two countries with extensive coastal deserts—Eritrea (a former colony of Ethiopia) and Somalia. The premise of the Manzanar project is that such coastal deserts can be converted to rich agricultural fields through the culture of microscopic algae (blue-green bacteria) in seawater ponds, and the cultivation of mangrove species valuable for their timber through seawater irrigation.

#### CONVERSION OF ALGAL BIOMASS TO SALTWATER FISH

Algae grow so vigorously that most algal specialists are preoccupied with preventing algal growth in swimming pools, reservoirs, and recreational lakes. We can deduce that algae are extremely efficient in scavenging nutrients and using sunlight for photosynthesis. The problem is then not how to grow algae but how to ensure that only desired algae grow to any significant extent and to convert their protein, carbohydrate, and vitamins to products useful to man.

Our first approach was to convert algae to fish. In 1987, during Eritrea's war of independence from Ethiopia, one of us (G. S.) went into rebel-held areas to assist in food production. Simple ponds were dug along the shore to a depth of about 1/2 m below the low tide line and about 200 m<sup>2</sup>. The ponds were filled with seawater, fertilized with chemical fertilizers to grow algae, and inoculated with mullet fingerlings at a rate of one fingerling per square meter. After 4 mo., each fish weighed about 1 pound. Less than 1% mortality was detected among these algae-eating fish, which are famous for their hardness in resisting disease and low oxygen concentrations. This is equivalent to a rate of production of about 15 tons per hectare per yr and demonstrated that desert shores could produce enough food

to justify cultivation on a large scale. This was not surprising. In Southeast Asia, freshwater ponds have been fertilized to grow algae and inoculated with algae-eating fishes for centuries. Our only variation on this time-proven practice was to substitute seawater for freshwater and marine fish and algae for freshwater fish and algae.

#### ARTEMIA SALINA (BRINE SHRIMP) AS AN INTERMEDIATE

Another of our approaches has been to use the brine shrimp, *Artemia salina*. The brine shrimp is a small branchiopod that reaches a length of about 1.5 cm and a weight of 10 mg. It is extremely salt tolerant. It is avidly eaten by fishes, shrimp, birds, aquatic insects, etc. For this reason, it would be an excellent food stock for most aquaculture or agriculture venture. If it is preyed on by so many of its fellow denizens of the wild, how does this hapless creature manage to survive as a species, and how can its strategy for survival be adapted to its large-scale production? The survival strategy of the brine shrimp is simple and effective. It begins life as a cyst on the banks of a dry pond devoid of predators such as fishes, aquatic insects, and birds. The cysts remain viable in the dry state for many yr. When the rains come, the cysts hatch in about 24 hr, and the hatchlings begin to filter-feed on the microscopic algae that grow in the pond. In about 10 d they reach sexual maturity and reproduce at a rapid rate. The females produce about 100 live young, nauplii, per d when the salinity is below 8‰. As the salinity approaches 8‰ through evaporation, the females switch from producing live young to producing cysts that cannot hatch at high salinity. The cysts are washed onto the banks by the wind, and the pond evaporates to dryness. The strategy for survival of the species is: 1) begin life without enemies in a dry pond as cysts, 2) hatch quickly when the rains come and in a short time reproduce at a rapid rate, 3) live in

<sup>1</sup>To whom correspondence should be addressed.

water so salty as to exclude many potential predators, and 4) end the cycle as an unpalatable dry cyst that awaits the next rain. We have mass cultured brine shrimp using a strategy similar to that of brine shrimp in the wild.

#### MASS CULTIVATION OF BRINE SHRIMP

Brine shrimp cysts from the Great Salt Lake, Utah, were purchased from the Petco Corp. (San Diego, CA, USA) and were used to generate the initial brine shrimp populations. The work was carried out on Halib Island about 30 km offshore from Assab, Eritrea, on the Red Sea. Three ponds, each about 200 m<sup>2</sup>, were dug to a depth of about 0.5 m below the low tide line. The ponds were about 20 m from shore. Water seeped into the ponds through the soil. Tidal variation at Assab averages about 0.5 m, and rainfall averages about 2 cm per year. Both conditions are favorable for brine shrimp production because rapid salinity changes are not effected by rain or exchange with groundwater, and fertilizer losses through leaching are minimized.

When water first enters the pond, its salinity is about 6‰ and rises to about 8‰ after 3 wk, the length of the production cycle. The cycle was initiated by pumping the ponds to near dryness, leaving about 1 m<sup>3</sup> in a depression. Five hundred grams of laundry detergent (Omo), was dissolved in the residual water, and with a pump the pond was washed with detergent. In some cases, 300 g of sodium hypochlorite was also added. Water re-entered the pond by seepage and reached sea level in 1 d. At this point, 200 g of adult brine shrimp were added, and di-ammonium phosphate was added at a rate of 2.5 kg per 3 wk or about 120 g per d.

Within 4 d, the ponds were visibly green with algae, and peak algal density was reached in about 10 d. At first the algae grew faster than they could be consumed by the brine shrimp, but the brine shrimp population overtook the algae at about Day 20 of the cycle. The pond suddenly cleared of algae, and the brine shrimp were harvested, drained, and weighed. We harvested the bulk of the brine shrimp by attracting them to the light of flashlights suspended over the edge of the pond. The aggregated brine shrimp were easily harvested with a scoop net. The remainder of the brine shrimp were harvested by our pumping out the pond through a chiffon filter. The pond was washed with detergent, and the cycle repeated.

Brine shrimp yields were 17.6, 13.0, 12.8, and 11.7 kg wet weight per 21-d cycle per 200 m<sup>2</sup>. The results extrapolate to the equivalent of 10 to 15 metric tons per hectare per yr. This has great promise for rendering desolate desert land productive. Brine shrimp can serve as food for a diversity of marine organisms such as fish and shrimp and could serve as a major source of protein for chickens, cattle, and goats. This work was carried out without benefit of electricity or pumps for aeration. With proper equipment, we predict that much higher yields can be routinely achieved.

#### PREDATORS AND PARASITES

When the ponds were first established, aquatic beetles were observed momentarily surfacing to take air, and quickly diving to covert positions on the bottom. When one beetle approximately 1.0 cm long was placed in a seawater jar with 20 adult brine shrimp, the brine shrimp were all consumed within a few hr. The beetles were attracted to the light of a flashlight at night. A trap was constructed with an inverted glass funnel illuminated by a flashlight. The beetles would

enter the large opening of the funnel and drown in a submerged chamber. When such a trap was deployed for three successive nights, many beetles were caught, and beetles could no longer be observed surfacing during the d. Dead immature beetles were also observed in the detergent wash water.

#### CONTAMINATION BY WILD OR TOXIC ALGAE

The predominant algae in our ponds were identified as *Synechococcus* (about 80%), and *Dunaliella* (about 20%). They are obviously appropriate food for brine shrimp. This observation draws attention to the unpleasant possibility that the ponds could be overtaken by toxic algae. To test the possibility that some degree of control could be exercised over the composition of the algae population in the ponds, one pond was washed with detergent and the other pond was washed with detergent and hypochlorite. The ponds were fertilized in the usual manner. The pond washed with detergent was dark green after 10 d while the pond washed with detergent and hypochlorite was not even faintly green. This indicates that when ponds are washed with chlorine they are virtually devoid of a starting population of algae, and that in the future we can control the algae population by controlling the inoculum.

#### NOVELTY OF THE APPROACH

Our approach to the mass culture of brine shrimp and algae differs in basic respects from current practice. Mass culture of brine shrimp is usually carried out in expensively constructed concrete raceways elaborately equipped with air and water pumps. The refinement of raceways has gone so far as to include elaborate traps for sequestering and eliminating brine shrimp feces. For lack of mass cultures of algae, due to the conventional belief that large outdoor ponds are not feasible due to contamination, brine shrimp are fed artificial diets such as finely milled rice bran (2). In contrast, we have used simple ponds, taking advantage of the vast area and abundant sunlight of coastal deserts to mass-culture algae and brine shrimp. Clearly, extensive use of the large areas of coastal deserts is indicated if algae and brine shrimp are to make a significant contribution to the food supply and wealth of impoverished regions of the world.

#### BATCH VERSUS CONTINUOUS CULTURE

We use batch culture as opposed to conventional continuous culture to minimize the time and opportunity for the entry, establishment, and eventual domination by unwanted algae, pathogens, and predators. Our batch cycle time of 3 wk is short, and our ponds are effectively disinfected by washing between cycles. We envision having considerable control over the composition of our algae populations by maintaining stock cultures in the laboratory, expanding them in moderate sized open cultures under selective conditions, and inoculating them into ponds that have been washed with chlorine. It should also be borne in mind that seawater microorganisms are removed as the water filters into the ponds through the soil. Currently we are using selection techniques for the improvement of algae stocks to obtain thermophilic algae that will withstand the highest temperatures possible and herbicide-resistant algae in the presence of herbicides (3,4).

#### MANGROVE FORESTS AS ALTERNATIVE FOR DECREASING RAIN FORESTS

Theories of global warming, polar cap melting and coastal flooding have been linked to global rain forest destruction and consumption

of fossil fuels. Remedies under consideration related to rain forests and reduction of consumption of fossil fuels are unlikely to be adequate for economic and political reasons. During the course of our work, we planted mangroves around the periphery of ponds to stabilize banks and at sites well above sea level where the trees are irrigated with seawater. We noted that in almost all cases the trees grew as well as in their natural habitat.

Our observations on the growth and function of mangroves in that context leads us to suggest that a replacement approach, e.g., to convert the great deserts of the world to mangrove forests, might be a more positive and politically, even economically, acceptable approach to counter deforestation. Mangrove trees grow in seawater, and in nature they grow in the intertidal zone. Growth is limited too far above the high tide line because they need seawater and too far below the low tide line because their roots need the air available at low tide. The need for tidal movement to bring air to roots is the probable explanation for the lack of mangroves in the Aegean Sea region where tidal variation is small. This suggests that mangroves could be cultivated on barren Greek islands if planted well above sea level and irrigated with sea water.

The growth requirements of plants are well known. Any plant can be grown on an inert substrate such as sand so long as it is watered with a solution at the right pH containing the known mineral nutrients, and the roots are provided with air. Mangrove swamps contain a dark mud in which organic material is continuously oxidizing and providing organic acids which slightly lower the pH below that of seawater. We propose that vast deserts such as the Sahara can be planted with mangroves and irrigated with slightly acidified seawater. In addition we propose that sewage sludge be incorporated in the soil around the trees to provide nutrients, mimic the rich organic muds of mangrove swamps, and solve the problem of sludge disposal. Some mangroves, such as some of the *Rhizophora* species, make good quality timber, which could be farmed as a renewable resource. The cost of moving seawater for irrigation will not be prohibitive. In freshwater agriculture, it is not uncommon to pump water from deep aquifers or to bring water from great distances through canals. Preliminary success has already been observed with growing mangroves in deserts with seawater irrigation (1). Barth and Lieth made extensive plantings above sea level alongside a channel for water from a reverse osmosis plant.

## CONCLUSION

Vast areas of the world are barren deserts with access to the sea, usually in impoverished countries. If brought into useful production, they would make a major contribution to breaking the cycle of poverty and overpopulation, one of the most urgent problems facing the human race. Taken together, the results we have achieved, the techniques developed, and the considerations raised all suggest that some of the most urgent and vexing problems of the world can be approached through application of simple technology applying the scientific method.

## ACKNOWLEDGMENTS

This paper is dedicated to Shingo Nomura of the Centre for Global Action whose aid enabled G. S. to start the Manzanar Project with Eritreans during their war for independence and to materially aid their efforts. The Manzanar Project is named after a relocation camp in central California where G. S. was interned during the Second World War and first began thinking of producing food in the desert. G. S. expresses gratitude and admiration to the current and former members of the Manzanar committee; Stanley Cohen, Lawrence Grossman, Niels Jerne (deceased), Tom Maciag, Rita Levi-Montalcini, Shingo Nomura, Jesse Roth, Martin Rodbell, Jonas Salk (deceased), Howard Schneiderman, Lewis Thomas (deceased), Susumu Tonegawa, Gary Trudeau, and Jim Watson for their courage and public spirit in lending their prestigious names in the endorsement of a project with high intentions, but uncertain prospects for success. We thank Richard Petterson of the Hydro Corp. for donating cargo ship spillage of di-ammonium phosphate. G. S. thanks Charles Crocker, David Rammner, and the Mary A. Crocker foundation for enabling him to start brine shrimp culture on the Salton Sea. We thank Petros Solomon, Eritrean Minister of Fisheries, for encouragement and support. Currently, the Ministry of Fisheries is supporting the development of a 10-hectare site for algae, brine shrimp, and mangrove production.

## REFERENCES

1. Barth, H.; Lieth, H. Studies on aquatic vascular plants. In: Symoens, J. J.; Hooper, S. S., ed. Brussels: Royal Botanical Society of Belgium; 1982:235-239.
2. Lavens, P.; Sorgeloos, P., ed. Manual on the production and use of live food. FAO Fish. Tech. Pap. 361; 1996.
3. Shinohara, K.; Zhao, Y.; Sato, G. H. Advances in gene technology: Molecular genetics of plants and animals. In: Downey, K.; Voellmy, R. W.; Ahmad, F., et al., ed. San Diego: Academic Press; 1983:327-332.
4. Zhao, Y.; Qian, K.; Sato, G. H. Advances in gene technology: Molecular genetics of plants and animals. In: Downey, K.; Voellmy, R. W.; Ahmad, F., et al., ed. San Diego: Academic Press; 1983:333-347.