Aquaculture Site Selection in the Caribbean: An Engineering Viewpoint

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ABSTRACT

Their have been guidelines published which address mariculture project site evaluations, as well as economics, governmental roles and social settings. Most, if not all, of these guidelines assume the use of ponds and pumps for water supply.

The islands forming the northern and eastern boundaries of the Caribbean provide a unique environment in which to perfect in-situ farming techniques. They provide a bountiful supply of clean, ocean water with predictable current which can be utilized for water exchange. In addition, many have access to water in excess of 200 m depth which can provide basic nutrients, potential energy and bacteria free water.

This paper will address methods of planning a mariculture operation using power consumption and operating costs as important criteria for site selection. Net impoundment methods pioneered in Japan, and more recently tested in Florida for raising seaweed, would seem to be appropriate for raising many products using currents for water exchange. Some alternatives for using temperature differentials available from deep ocean layers will be discussed in light of other experience. Specific sites in the Caribbean will be used as examples of the possibilities.

Illustrations of different types of existing or planned operations (in-situ vs. land based) and their operating costs will be presented to highlight the importance of power consumption to operating costs.

INTRODUCTION

Since 1983, the Division of Applied Biology at the Harbor Branch Oceanographic Institution (HBOI) has engaged in research and development of the culture technology of various marine algae, finfish, molluscs and crustaceans. The Division's Engineering department has designed and built facilities, equipment and hydraulic systems to support these varied mariculture projects. In addition, a mariculture facility was designed and built in Antigua, W.I. While only the mollusc hatchery at HBOI in Florida has been expanded to commercial scale, the difficulties involved with the design, construction and maintenance of these land-based facilities have become evident.

An aquaculture facility, whether commercial or equipped for research, is essentially a life support system. While the aquaculturist works to maintain water quality and purity in his culture system, the engineer must maintain a continuous, consistent quality water supply in whatever quantity is required for the aquaculture production undertaken.

At HBOI, situated on the Indian River lagoon on Florida's Atlantic coast, water must be pumped about one kilometer to the Division's aquaculture facility. At such distances, the volume of water which can be pumped economically is severely limited. In addition, the primary water supply system is redundant for several reasons. Biofouling inside saltwater lines increases pumping costs by effectively reducing pipe diameter and increasing drag on water flow. Dual lines permit routine alternation of pipes, weekly in our case, so that organisms in the pipe die and can be flushed from the system. Dual pump systems assure a backup readily available in case of breakdown and, more importantly, provide time for routine maintenance and repair of equipment during the off cycle. If all of this sounds expensive - it is!

The shallow depth, limited flushing and extensive coastal development along the Indian River lagoon results in highly variable water quality available to the HBOI aquaculture facility. Drainage canals discharge large quantities of freshwater from low lying agricultural and residential areas further inland which can result in drastic drops in salinity during periods of heavy rainfall. Cool winters and warm summers cause a wide variation in temperature in the shallow, poorly flushed lagoon. These natural phenomena, in tandem with man-made nutrients from coastal development and toxic chemicals from agriculture industries, often make it necessary to resort to closed, recirculating saltwater systems for some mariculture projects.

While the technology for intensive, recirculating systems is available, they are often expensive to build, operate and maintain. Also, since the culture water is continuously recycled, the potential that a single diseased organism could create a catastrophic epidemic throughout the culture system becomes very real. Therefore, recirculating culture systems are far more complex than flow-through systems. Additional components usually include protein skimmers, biofilters or activated carbon filters to reduce organic loads and water sterilizing systems, such as ultraviolet lights or ozonation. The additional complexity and maintenance requirements are representative of a number of conditions which create what is known as an "aquaculture ulcer" among the engineering staff.

CARIBBEAN ADVANTAGE

The characteristics of Caribbean water are derived from the North Equatorial Current of the Atlantic Ocean, along with the admixture of some water from the South Equatorial Current (Sverdrup, *et al.*, 1946). In both cases, the water is clean, and exhibits the stable physico-chemical characteristics of oceanic waters. Salinity, for example, remains stable year-round at around 35 ppt. The exceptions to this are in the vicinity of the coast of South America, where runoff from the great rivers add low salinity water, sediment and nutrients. In addition, upwelling phenomena occur much of the year along the north coast of South America. A strong current moving northwest along the coast of French Guiana and Surinam rounds the coast moving west into the southern Caribbean, causing that area to be less stable, but more productive than nutrient poor surface waters to the north (IUCN/WWF, 1962).

Surface temperatures remain stable between 24°C and 28°C throughout much of the year in the Caribbean. However, in naturally impounded shallow areas with sluggish currents, hypersaline conditions and temperatures exceeding 40°C have been reported (Creswell, pers. comm.). Most of the Caribbean is bathed by strong currents of warm water from both the North and South Atlantic. In particular, the island chain forming the northern and eastern boundaries of the Caribbean enjoy steady easterly and southeasterly currents of up to 1.0 knots all year. The western and southern boundaries bordered by Central and South America form a barrier which, along with the island of Cuba, funnel the currents through the Yucatan Channel, the only outlet. The vagaries in the coastline, particularly in Central America, cause more variation in both velocity and direction in those areas. If, for aquaculture, an unlimited source of clean, stable water is high on the priority list, the Caribbean would be an excellent place to look for sites.

Another advantage worth mentioning here is the existence of a deep (> 200 m) layer of cooler nutrient rich water underlying the warm surface water, which is relatively low in nutrient content. The island structure is such that this depth occurs in many places within 1.5 kilometers or less from the shore. The temperature difference at this depth is about 8°C (15°F).

CULTURE METHODS

For engineering purposes, there are only two principal types of culture methods: 1) land-based systems which require tidal flushing or water pumps, and 2) in-situ systems, such as impoundments or cages moored in open water. Both methods have their advantages and disadvantages which may be quite different depending on the species being cultivated.

Both land-based and in-situ culture systems have initial capital costs for material and construction of the facility. Land-based methods, typically ponds or raceways, require earthmoving for construction, sometimes a pond lining material if the soil is too porous and a network of supply lines, pumps and effluent drains. An emergency generator is necessary with adequate power output to maintain the "crop" in the event of power loss from the municipal electricity system, if indeed there is one available. Both methods of culture probably will require a building for storage of equipment and supplies.

In-situ culture will require material for construction of impoundments or cages, or the purchase of these items from specialized companies which fabricate and market aquaculture equipment. An impoundment might be constructed using dredged materials to form a wall or breakwater. A vessel for tending the impoundments or cages will be necessary unless cultivation can be accomplished in shallow water or intertidally.

Since either type of facility must function continuously as a life support system, equipment maintenance is a vitally important component. Here, simplicity of design is an important factor when designing an aquaculture facility. A less complex system is generally easier and less expensive to maintain. The in-situ method will be subject to fouling and some natural physical damage, such as flotsam or storm seas. Natural damages can be minimized by careful site selection and design. Fouling problems may require constant attention in some areas, but system design and regular cleaning usually can keep the problem in check.

Maintenance of land-based aquaculture systems become increasingly complex in proportion to the number of components in the system and how they interact. Care of machinery, such as water pumps, aerators and electrical generators, are critically important since the survival of the entire crop may be jeopardized during equipment failures.

The cost of facility operations is going to be a constant overhead expense, an important fact to consider during the site selection process. Land-based facilities require energy to supply water and aeration. Consider a one hectare pond, one meter deep or 10,000 m^3 in volume, which is exchanged once per day. If the pond were next to the ocean, and only three feet above sea level, the theoretical power required per exchange would be 25.54 kwh. The "real" power requirements, taking pump efficiencies into consideration is 42 kwh. At two meters elevation, the theoretical energy requirement is double, but real power requirements increase at a higher rate because pump efficiency decreases as head pressure increases. At 10 m head, theoretical power demands to pump 10,000 m^3 are 255 kwh, while "real" power consumption climbs to 748 kwh (Figure 1).

Distance of the pond from the water source, flow rate and pipe diameter also affect pumping costs. Consider the one hectare pond at one meter elevation. If the pond were 10 meters distant from the water source, the additional power required to push water through the pipes at the required 6.94 m^3 per minute (100% exchange per day) is 1198, 149.7, 37.4, and 13.5 kwh for 4", 6", 8" and 10" pipes, respectively. If the distance is 50 meters - multiply by five. Although pumping costs decrease with increasing pipe diameter, the high capital costs of installing large diameter pipes for redundant intake lines must be considered (Figure 2; Engineering Formulas and Table).

Projected power demand and costs based on municipal utilities or local fuel prices (if the facility must generate its own electricity) are noteworthy when choosing a location for an aquaculture venture. Electricity in Florida costs about

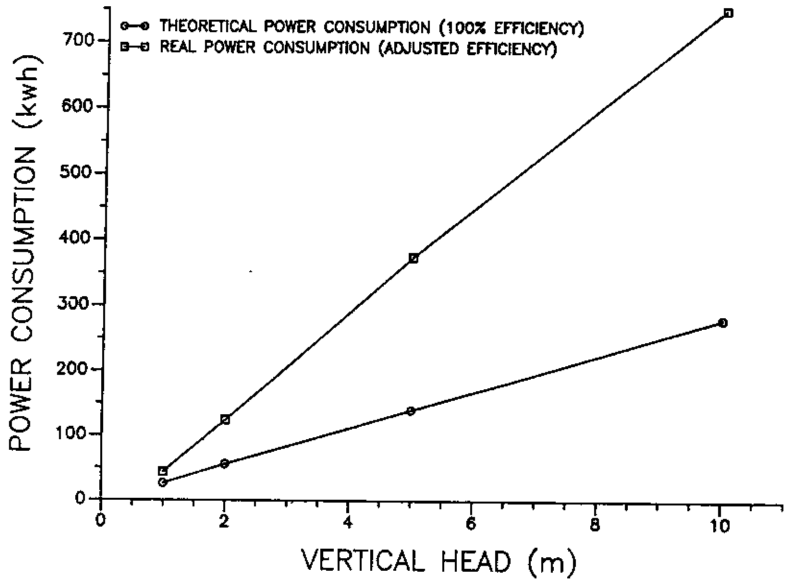

Figure 1. Theoretical and real power consumption (kwh) vs. vertical head.

$0.08 per kwh. In many countries in the Caribbean the consumer must pay four to five times that. For convenience, consider a cost of $0.10 per kwh. Should the pond be located at one meter elevation and one meter from the water source, the daily power bill for one hectare - one meter deep (10,000 m^3) would be $4.28 + $11.98 = $16.26 using 4" pipe. At an elevation of 10 meters and 100 meters from the water source pumping costs would be $74.80 + $13.48 = $88.28 using 10" pipe. Clearly, elevating water is very expensive, regardless of design and planning. The operational costs of moving water horizontally can be controlled somewhat, but at the expense of increased initial investment. A broad ditch or canal, again more expensive than pipe to install, would require no additional power.

If the one hectare - one meter deep containment were located in the sea, such as net or seawall impoundments or rafted fish cages, the same exchange

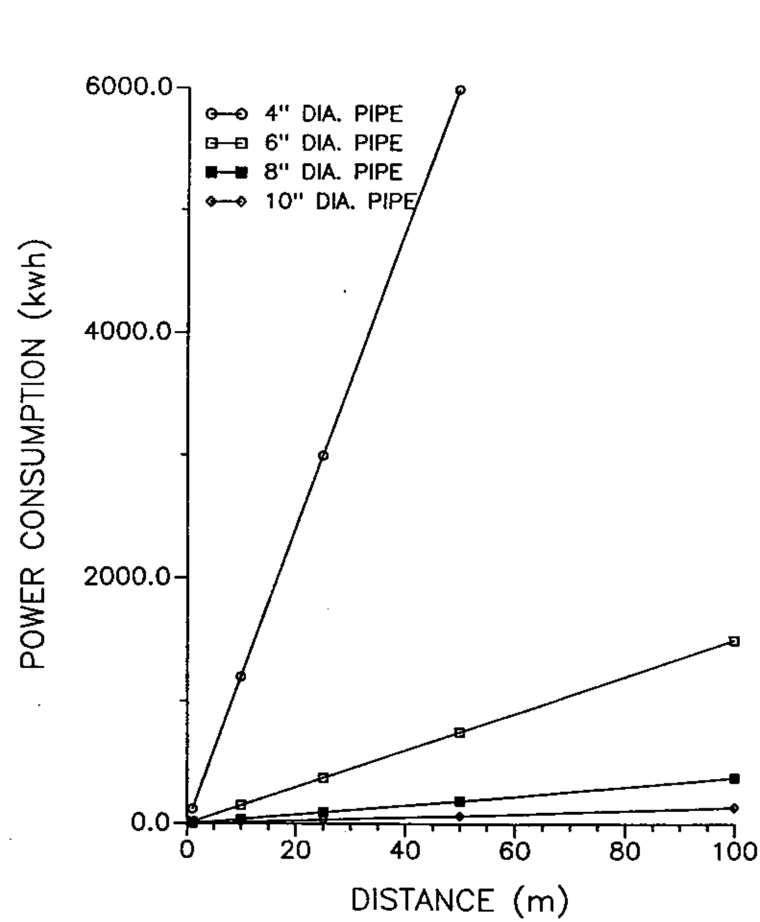

Figure 2. Power consumption (kwh) vs. distance (m) for various pipe diameters.

rate (10,000 m^3 per day) would be accomplished by a current of 0.002 knots. To illustrate, HBOI has a one acre (0.405 hectare) shellfish lease in the Indian River Lagoon where one million clams have been bottom-planted. The lease is located several kilometers from an inlet to the ocean, it is approximately one meter deep and water movement is wind and tidal driven. It has been determined that each clam requires 75 to 115 liters/day to sustain adequate growth. For one million clams the requirement is about 25,000,000 gallons/day. A 0.07 knot current over the one acre lease would provide that exchange. In contrast, pumping that water into a low pond over a one meter embankment would cost $38.40/day, or about $0.014/clam/year. If the pond were 10 m above sea level, the cost increases to $0.20/clam/year, or more than the market value of the product.

Freshwater aquaculture normally uses water from streams or rivers to exchange ponds or raceways. This is supplied through precipitation, a natural distillation process. A man-made distillation system capable of delivering 10,000 m^3, or one exchange of our hectare pond, would consume 6,900,000 kwh of electricity at a price of $690,000 or the equivalent of 70,000 gallons of gasoline, or 108 hp expended continuously for a year (Taylor, 1956).

SITE SELECTION

Because of the method of culture, land-based or in situ, care must be taken during the site selection process to assure an adequate supply of quality seawater. Avoidance of municipal and industrial effluents up current from the site is obvious. A less obvious example is resuspension of fine calcareous silt, common throughout the Caribbean during periods of rough seas, which greatly elevates turbidity. Extensive shallow flats, particularly on the lee side of many islands, may contain heavy silt loads for many days or weeks (Chaiton, pers. comm.). Pumping sediment laden water quickly clogs filters, increases maintenance costs and jeopardizes the health of the organisms in the culture system.

Currents around the island chain are essentially east-west, so locations on the windward (east) side, or in many cases at the northern or southern ends of an island, are to be preferred if access to oceanic water is a priority. In situ culture can be conducted in bays and lagoons which, although protected, have ready access to clean water. Cage culture can be conducted behind barrier reefs or toward the lee side of an island as long as water quality is not compromised. Natural bottom configuration is a factor in impoundment type systems, unless the culture plan calls for alteration anyway to provide bottom features, such as specialized habitat.

Land-based pond systems should be close to the water source, and at low elevation. Careful attention must be paid to power availability, reliability and cost. These factors will have a continuing effect on operating costs, and therefore, the economic viability of the project.

A noteworthy consideration for use in the site selection process is the use of nutrient rich water from deeper layers. The deep water not only contains nutrients, but it is free of parasites, pollutants, predators, pathogens, epizoites and epiphytes. It is being used in Hawaii as a co-product of the Ocean Thermal Energy (OTEC) Project on the island of Hawaii. It has also been used on the island of St. Croix to produce microalgae as a feed for filter feeding molluscs.

Nutrient concentration reaches a peak at slightly less than 1000 m depth, although there is evidence of a significant concentration of nutrients at about 200 m (Parsons *et al.*, 1977). Of engineering importance is the temperature differential of this cooler water. At 200 m it is about 8°C (15°F) and as much as 20°C at 1000 meters. While the OTEC projects have not produced commercial quantities of electric power, they have illustrated that the materials and technology do exist to produce useful power from the potential energy which exists in the depth related temperature differential in ocean waters.

This potential power can be calculated. At the rate of 378.5 l/min (100 gal/min) and a temperature difference of 8°C (15°F) the theoretical horsepower available is 302 hp. The theoretical horsepower required to pump that quantity is 0.025 hp. The efficiency of a reliable, inexpensive machine to convert the potential energy to do nothing more than pump the water would have to be less than one percent - well within the capability of modern technology.

The depth from which the water is pumped has much to do with site selected, as the length and size of pipe required impact capital costs. One kilometer of 30 cm (12") diameter plastic pipe would cost approximately $20,000 at current US prices. A pair of 1.5 km, 30 cm diameter pipes ($60,000) would produce essentially no suction head to a flow of 544 m^3/day (100 gpm). The St. Croix project produced the equivalent of over 8 tons/ha/yr of microalgal protein from the water pumped from 870 m, and projected over 20 ton/ha/yr with improvements in methods and equipment (Roels et. al., 1979). As reliable, economical equipment becomes available to utilize the temperature differential for pumping, initial costs will be far less significant, and the practice of using deep water nutrients will be more widespread in the Caribbean.

CONCLUSION

While much remains to be learned, the Caribbean basin has the requisites to be a major world center for warm water aquaculture production. In situ culture can start any time and more intensive methods will follow as facilities and equipment are developed. Research in St. Croix has demonstrated that serial polyculture can be accomplished in the Caribbean. The technology exists to begin the planning, equipment development and site location which, with the cooperation of the many governments of the Caribbean, can turn the area into an aquaculture production center.

LITERATURE CITED

International Union for the Conservation of Nature. 1962. Planning a marine conservation strategy for the Caribbean basin.

Parsons, R. T., MK. Takahashi and B. Hargrave. 1977. *Biological oceanographic processes.* Pergamon Press, Oxford. 332 pp.

Roels, Oswald, J. Sunderlin and S. Laurence. 1979. Bivalve molluscan culture in an artificial upwelling system. *Proc. World Mariculture Soc.*

10:122-138.

Sverdrup, H.U., Johnson, M. and R. H. Fleming. 1946. *The Oceans: Their physics, chemistry and general biology.* Prentice-Hall, Inc., New York. 1087 pp.

Taylor, G.F. 1956. *Elementary Meterorology.* Prentice-Hall, Inc. Englewood Cliffs, N.J. 364 pp.