The Design of An Aquaculture Enterprise

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INTRODUCTION

Often the decision to undertake aquacultural enterprises is achieved after too little consideration of the many severely limiting factors and clear and present risks that confront such ventures. Probably the initial critical determination that must be made, with a certain degree of quantitative assurance, relates to the marketability of the aquafoods to be produced. Without a market there can be no enterprise. Almost of equal significance is the state of the production technology to be used — "seed" procurement, grow-out techniques including nutrition and feed supply, disease control, predator management and harvesting. Processing technology and product development skills are additional major requisites.

However, not the least significant of the essential considerations required are the numerous, demanding and diverse site selection criteria that must be satisfied in order to accomplish a successful aquabusiness. I shall limit my comments primarily to this subject although I shall have to allude to the other matters noted above as they bear directly on making the site selection decisions.

The choice of a location in which to grow aquatic animals commercially has often been dictated by personal, and sometimes parochial, preference for a particular site; by fortuitous ownership or accessibility to a plot of land; by superficial and casual analysis of the requirements or even merely by capricious or whimsical judgment. Such a critical decision should instead be determined by the most comprehensive analytical procedures that can be applied. We must start with a detailed understanding of the life-cycle of the animal to be reared, so as to define, with some reasonable level of confidence, the tolerance limits within which the various environmental parameters can vary. Given an understanding of these biologically imposed limits, the best cultural technology that is available to accomplish optimum growth and economic production will then define additional site requirements.

To realize the high return on investment that aquaculture, as a new high risk venture, should provide, we have found that a certain economic scale must be achieved. The moderately large size of the production facility, and consequently, the considerable quantity of animal product to be produced, suggest that vertical diversification into a processing plant and marketing of a diverse product line may be a wise course to follow. When the site requirements for processing and marketing are then added to the requisites for the production units, the list of site selection criteria will be expanded greatly.

Presently in the U.S. and in Europe, aquacultural enterprises are generally conceived as monoculture systems in which one animal is to be reared in an improved and managed environment. On the other hand, in several Asian and Israeli culture schemes polyculture is extensively practiced. There, two or more animals, occupying different and non-competitive ecological niches, are grown simultaneously in the same controlled environment. These animals may share similar tolerance limits such as water temperature and salinity, but they feed at quite different trophic levels. An outstanding example is the various species of carp which, when grown together, do not interfere with each other, but rather the growth of all species is enhanced by virtue of each contributing in its peculiar way to the maintenance of a healthy community and environment.

On the other hand, the occupants of the culture facility may be of widely different phyla, such as molluscs, crustaceans and finfish all growing together with no ill-effects but, in fact, with symbiotic or commensal associations that considerably increase yields of each species over those achieved with monoculture.

If we intend to practice polyculture, an even more discriminating choice of site must be made than if our culture system is planned to grow only a single species.

We have been guided, to a considerable degree, in developing the total strategy for an aquaculture industry by the experience with terrestrial animal husbandry. However, the real and very significant differences between air and water growing media must be recognized and factored into the risk analysis of aquaculture ventures. Technologies have been developed, or are evolving, in the aqueous environment that are functionally analogous to terrestrial animal husbandry technologies, without necessarily being homologous in physical structure. We can list these in terms of increasing levels of intensity of culture.

RANCH MANAGEMENT OF AQUATIC ANIMALS

The most extensive system of aquatic animal management that can be considered aquaculture, is to utilize natural water embayments or sheltered coves, in either fresh or saline waters, as the open range was used in early western ranching. Considerable tidal flushing or other hydrological means of maintenance of water quality is desirable. Minimum use of confining nets or fences will be required by the appropriate sites. Young animals are released onto the range to forage or browse in quest of natural feed. Stocking may be from captured fry or from hatchery stocks derived from induced spawning.

An essential environmental management requirement is to control predation and competition in the natural populations that share the environment. This is usually accomplished by chemical means. Limitation of pollution of natural coastal lagoons or bays is usually difficult, but it must be done. Fouling and storm damage to confinement structures must be avoided. Capital and feeding costs are low, but yields are also quite low, and therefore an extensive area is required to yield sufficient volume of product to justify the undertaking.

The selection of a location for such a system of aquaculture demands not only that extensive areas be ecologically suitable, but that they be free of competitive uses, unpolluted, legally and socially available, amenable to surveillance and have sufficient natural productivity to support large populations of the crop animal.

Harvesting usually entails the labor-intensive practices and high costs of the cattle round-up, but since the areas are large, the gear and methods of traditional commercial fishing may be employed.

STATIC POND OR POOL AQUAFARMING

The next more intensive system of culture is the static pond method that is engineered to confine dense populations of crop animals in earthen, concrete or otherwise structured ponds or pools. Here, because of the large biomass per unit volume of water, reliance on natural productivity alone is usually not adequate to support the large number of crop animals which must be grown to justify the investment. Natural productivity of static ponds is a function of the indigenous population of plants and animals, the fertility in the water and the intensity, quality and duration of sunlight. Therefore, a supplemental or a complete diet must be brought and distributed in the ponds to ensure sufficient yields.

The considerable amount of earthwork for pond construction, water supply and drainage canals imposes rigorous demands on the site selection mission to find appropriate soils and topography to minimize construction costs.

The lentic or static pond, whether it is filled with fresh or saltwater, is, for the most part, a closed habitat as opposed to a cattle range or even a feed lot. Toxic or deleterious materials when introduced can accumulate by recycling into the energy chain, and become ultimately concentrated in the crop. This is particularly true if it is a secondary carnivore such as channel catfish. Persistent pesticides, for instance, may be introduced into the system in the feed, leached from the soils, blown in from crop dusting or added with make-up water. Once they have entered the lentic habitat they are likely to remain until they are removed in the harvested crop. These considerations impose further important concerns for the site selection strategist. Nonetheless, even with the added cost of feed, pond construction and toxicants, static pond culture is still a major freshwater aquafarming technique.

RACEWAY CULTURE

When an abundance of flowing fresh water is available or where strong tidal flushing can be utilized, the accumulation of metabolic wastes and toxic agents can generally be greatly reduced; and other limiting environmental stress conditions, such as oxygen depletion, can be considerably mitigated. Lotic habitats that can serve as sites for raceway systems are indeed sought and vied for. As an alternative to natural gravity flow or tidal movements to transfer water, one can turn to mechanical pumping, using diesel-electric power. Of course, if one is fortunate enough to locate the aquafarm at the effluent discharge of an electric power generating plant, pumping costs can be shared with, or totally borne by, the power production function.

The use of power plant effluents is applicable to both fresh or saltwater aquafarming. The heated effluents of power generating stations can provide the essential input into an environment that might otherwise be unsuitable for commercial aquaculture because of the low winter water temperatures. A properly managed outfall of a power plant can be mixed with ambient-temperature water to adjust the culture water temperatures to a desirable range for the favorable growth of the crop throughout the year. This, then, can be the determining factor in a given site selection decision. In raceway culture a complete ration must be provided, for little natural productivity is available in the fast flowing water within the raceway.

CAGE OR BASKET CULTURE

Still another technology that is rapidly gaining wide acceptance for certain finfish and crustacea is to confine the animals in wire mesh or net cages, suspended or supported in rather large water bodies. Lakes or sheltered ocean bays have been used successfully, and recently cages suspended in fast flowing canals and other waterways have yielded very high productivity, with good economics. In cage culture, as in raceways, very little reliance can be placed on natural productivity, and consequently a complete nutrient ration must be supplied. The site requirements for cage aquaculture are in many ways more demanding than static pond systems. The institutional constraints resulting from legalized, but competitive, uses of aquatic environments impose on aquaculture generally, but cage culture in particular, the adverse effects of urban and industrial uses, navigation, waste disposal, dredging and mining and sport and commercial fishing. These may well become the limiting factors in site selection for cage culture, and often limit the siting of other systems of culture as well. In cage culture, the easy access to the crop may invite poaching, and therefore surveillance requirements impose additional site selection demands.

CLOSED HIGH-DENSITY CULTURE SYSTEMS

Even more intensive culture systems, which employ entirely closed, water recycling mechanisms, are being developed and used commercially. They are, therefore, less dependent on large volumes of clean natural water, and consequently demand less stringent environmental conditions. In closed systems, the culture water is cycled through biological and mechanical filters which purify it for reuse. This practice is justified, particularly when the water supply is limited or the water must be heated and the calories conserved. The use of closed systems probably can more readily avoid the introduction of heavy metals, persistent pesticides and other pollutant materials. Such systems may ultimately prove to be preferred as suitable natural environments become scarcer, and higher costs become more readily tolerated. The high capital investment demanded by closed cycle systems of culture generally can be justified only when sites for more extensive systems are no longer available, and when the productivity is commensurate with high production costs, and when the products that are produced can demand high market price. For such intensive, high density systems, site selection criteria become less limiting, but nonetheless the decision is critical, since we are never entirely free of the physical environment nor can we neglect the economic, political and social environmental influences.

Whereas filter feeding organisms, such as the molluscs, certain crustaceans and some true fish, can make a living from naturally occurring phytoplankton alone, the carnivorous fishes, such as the salmonids and flatfishes (which are confined in raceways or closed culture systems), must be provided with nutritionally complete rations. Even in this latter case, site selection is not entirely freed from feed considerations, since proximity to raw materials supply for on-site formulation, or the cost of transport of pelletized rations from off-site sources are important location considerations. Intermediate between these extremes are certain warm water, fresh water animals, such as the catfish (Ictalurus), which can garner a great deal of their feed from naturally occurring production in the culture pond, and thus require only a diet supplement.

A CHECK LIST OF CRITERIA

The following checklist of site selection criteria cannot be readily ranked into any priority order because different requirements among species will significantly reorder the list. Cultural technologies will also reorder the list, and geographical limits, however imposed, will materially change the priorities. It is a trial at assembling a comprehensive inventory of needs that attempts to include all kinds of environmental characteristics, and therefore the entire list need not be used for any given single site.

The list of site selection criteria grew out of an experience which was not limited by species, systems or geography alone. Rather, it was dictated initially by market characteristics and requirements. The market, therefore, defined the size and shape of the enterprise to include certain species, whose cultural requirements could be met by certain cultural systems, which in turn could best be practiced in certain specially endowed environments. We then searched out that very special environment, to locate the particularly appropriate site that fulfilled most of the other requirements.

The list of criteria is offered with the expectation that it is as applicable to site selection in the Gulf of Maine as it is in the Gulf of Honduras or the Gulf of Thailand. That is, the list should have the universality which could make it useful in locating low, middle and high latitude aquaculture ventures in domestic and in foreign lands. I have been especially cognizant of private sector investment requirements in economically developing nations in the tropics where aquaculture is notably well suited, and where a successful venture can make a significant contribution to economic growth and rural development.

Many of the criteria noted here are so obvious that it may be insulting to bring them to your attention, but they must be included for completeness, to remind ourselves of the interrelatedness of the various components of an aquaculture business enterprise. This checklist is presented primarily to serve as a guide in planning. It is not offered as a recipe to be followed as a cookbook, but rather it should be viewed as a device to discipline the decision making process and thus, to aid in the establishment of sound businesses.

A CHECKLIST OF SITE SELECTION CRITERIA FOR AQUACULTURE

I. ECOLOGICAL PARAMETERS

- A. *The Physical Environment*
  - 1. Hydrological factors
    - a. Water properties
      - 1) Temperature range — diurnal, seasonal, annual variability
      - 2) Salinity range, osmotic concentrations, tidal and seasonal variations
      - 3) Solutes
        - a) Dissolved nutrients contributing to productivity
        - b) Dissolves gases, e.g., 0_2, CO_2, H_2S, NH_3
        - c) Toxic or deleterious compounds
      - 4) Bacteriological and viral content
        - a) Coliform organisms
        - b) Other microbiological contaminants
      - 5) Turbidity range, light penetration
      - 6) Color — light absorption
      - 7) Sedimentation — silt burden
        - a) Degree
        - b) Kind

8) Detritus content — inorganic and organic
9) pH, buffer system
10) Alkalinity
11) Hardness
12) Watershed characteristics
    a) Area gradients
    b) Cover, run-off
13) Ground water supply
    a) Aquifers
    b) Water table depth
14) Tidal flushing
    a) Rates
    b) Oscillations
15) Wave action range
    a) Storm to calm
16) Currents

2. Meteorological factors
    a. Wind — prevailing direction
        1) Velocities
        2) Seasonal variations
        3) Storms
    b. Light — total annual solar energy impingement
        1) Intensity of radiant energy
        2) Quality of light
        3) Photoperiod — diurnal cycles
    c. Air temperature — mean, minimum, maximum
    d. Relative humidity or dew point — mean, minimum, maximum
    e. Precipitation
        1) Rainfall amounts
        2) Rainfall annual distribution
        3) Storms
3. Edaphic factors
    a. Soil type — profile — subsoil characteristics to ground water table
    b. Percolation rate — coefficient of hydraulic permeability
    c. Topography
    d. Particle size and shape
    e. Angle of repose — wet and dry
    f. Fertility
    g. Microbiological population
    h. Leachable toxins, e.g., pesticides, heavy metal ions
    i. Color — infrared reflection — absorption

B. *The Biological Environment*
1. Biotic resources
    a. Primary productivity — photosynthetic activity
    b. Secondary productivity — number of trophic levels
    c. Total natural production as feed
2. Seed source from wild populations of species to be grown, e.g., spatfall, availability of gravid females

3. Eutrophication resulting in microorganism populations
    a. Natural origins
    b. Man-made origins, domestic and industrial

II. ECONOMIC CLIMATE

A. *Land*
1. Costs
2. Restrictions on ownership
3. Zoning regulations

B. *Labor*
1. Wages; minimum wages, severance pay, other fringe benefits
2. Availability of labor, proximity to production and processing sites
3. Union rules and government regulations
4. Liability laws
5. Availability of professional management
6. Availability of engineering skills

C. *Transportation*
1. Accessibility of facilities — length of haul to port or market
2. Road system for trucking
3. Railroad service
4. Shipping ports, cargo handling facilities
5. Airports, cargo handling.

D. *Materials and Services*
1. Raw materials supply
    a. Feed
    b. Fuel
2. Equipment availability
3. Service and maintenance
    a. Spare parts
4. Finished goods — import duties
5. Packaging materials availability

E. *Construction Costs*
1. Earth moving
2. Piping
3. Wells
4. Buildings

F. *Communications*
1. Telephone, telex, cable

G. *Power Costs*
1. Public power
2. Private production

H. *Financial*
1. Sources of capital

a. Commercial banks
b. Development banks
2. Operating credit
3. Financial controls
4. Constraints on movement of capital
5. Currency stability

I. *Markets*
1. Proximity to domestic and foreign
2. Trade practices

III. POLITICAL SYSTEM

A. *Stability*

B. *Government Service to Economic Development*

C. *Natural Resources Policies*

IV. LEGAL FRAMEWORK

A. *Incentives to Private Investment*
1. Tax abatement
2. Duty free import

B. *Constraints*
1. Equity limits
2. Fishing limitations
3. Water rights — riparian, ownership and lease conditions

V. SOCIAL PARAMETERS

A. *Competing Uses of the Environment*
1. Adverse effects of urban and industrial uses
2. Waste disposal
3. Power generation
4. Recreational uses
5. Mining— sand and gravel, petroleum
6. Dredging
7. Navigation
8. Irrigation
9. Sport fishing
10. Commercial fishing

B. *Customs with Respect to Use of Common Property Resources*
1. Redress of losses due to poaching

C. *Community Services*
1. Schools
2. Medical care
3. Housing
4. Protection
5. Cultural resources

The integration of the above criteria into a biologically and economically sound system of production, processing and marketing requires a benefit/cost analysis that at this time defies our capabilities. The essential hard data are just not available to us. Each of these criteria must be weighed in relation to all others, and even if we knew the range over which they could vary practically, we do not understand how the complex interaction would affect the working of an enterprise. That is, we are not sufficiently knowledgeable regarding interactions among these variables to weigh them wisely in an effort to estimate a benefit/cost ratio.

These variables are for the most part non-linear and in relation to each other; they form multi-dimensional spaces. The interaction plots are extremely complex and determining the optima is still beyond our skills. However, we should note that complex systems of production, such as these to which we refer today, have been undertaken by entrepreneurs who somehow intuitively integrated the components into a workable system. Not, however, without failures, which we must be prepared to confront, compensate and learn from. We may someday have sufficient command over this field of knowledge to enable us to build a mathematical model with sufficient verisimilitude to represent the real aquatic world, and guide us to efficient utilization of the living resources of the seas and the lakes so as to make a contribution to freedom from hunger. But there is much yet to be done.