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"FUNDAMENTAL LIMITATIONS TO THE SCALING-UP OF AQUACULTURE FACILITIES"

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ABSTRACT

The limitations of undefined objectives, finance, land and water, biodata, logistical resources, and significant experimental demands of pilot-scale facilities are discussed. Criteria for improved design are detailed.

L'auteur se décrit les limitations de les objectifs indeterminé, les finances, le terrain et l'eau, les specifications biologique, l'approvisionnement de ressources et les exigences expérimental significatif de les installations aquicoles à échelle pilote.

Il s'identifie plusieurs critères pour le dessein supérieur.

Introduction

Several fundamental and often unrelated factors inhibit the successful scaling up and design of aquaculture systems, particularly the large laboratory or outdoor research projects into pilot-scale facilities. These factors apply to both pilot-scale commercial production and enlarged research and development demonstration facilities. These fundamental limitations are: (1) the lack of clear objectives for the pilot project, (2) limited financial resources, (3) the lack of available land, limitations in water supply, or other physical constraints, (4) deficiencies in the biodata to enable correct calculations to be made, (5) the lack of the biological resources (the seed and feed) which reduce the practicality of the project, and (6) the demanding experimental designs for obtaining realistic results (replicate facilities and scale).

Limitations to Optimization

1. The Lack of Definition of Production Goals

The pilot project phase of a program is often developed without a specific definition of objectives. The extent of the options for the design of the proposed facility can differ depending on the level of success of the preceeding laboratory-scale operations, but the optional goals for a pilot-scale facility are: (1) obtain further technical research and basic development data for both biological and engineering systems, (2) maximize total production or facility yield, (3) produce a harvest which is large enough for quality control and market testing analyses, and subsequent economic evaluation, and (4) obtain management and operational experience related to the needs of commercial production. Many of these goals have been reviewed in detail by Mitchell (1980).

Most typical pilot-scale projects attempt in their operations to achieve all these objectives concurrently. However, to try to do so is a mistake. For example, fish reared to test different diets or in stock density trials are not necessarily the best individuals to use for a market test for quality. The fish may have been stressed or fed on a diet which affected the texture of their flesh and the consequences of a poor quality response at the market would be highly significant for the future of the project. Similarly, the growth rate of a population of selected fish fed well for a quality control test should not be used to establish average production curves for specific facilities.

A statement of definite objectives for a pilot-scale project increases the level of commitment and increases the chances for future implementation at an increased level of production. Furthermore, the data obtained from a facility pursuing a single purpose are more acceptable and accurate than one with a multiplicity of concurrent goals.

2. Limited Financial Resources

Undercapitalization of the design and construction of pilot-scale projects in aquaculture has often caused the failure of the facilities to perform and function adequately, or to enable them to yield worthwhile results in a reasonable time. Specifically, small or poorly designed facilities have reduced the chances of pilot-scale trials to be repeated accurately or interpreted and extrapolated correctly into economic data for large-scale farming systems. Although pilot-scale facilities can be phased over a period and units added incrementally, the small facilities can only respond to clear objectives and carefully planned use.

The long growth period of aquatic animals to market size (mostly above 12 months), and the even longer period to sexual maturation, make trials at the pilot-scale level more expensive than almost any other food producing agriculture system. The need to support a pilot-scale operation for five years to obtain repeatable results and to learn the new management techniques is financially demanding, Such an operational investment is not particularly attractive to an individual farmer. The corporate investor can withstand the operational and maintenance expense of the long-term pilot project more readily. However, he is often more interested in a faster return on investment and consequently unwilling to commit a large amount of capital on facilities to show no gain other than tax benefits for five years.

The pilot project operating costs are also complicated and increased by the additional expenses of the peripheral activities. For example, additions to the hatchery of larval food requirements to increase production of seed, new staffing arrangements, and feed and feed storage logistics add considerably to the total cost for a five-year pilot-scale program.

Pilot-scale construction, whether for research or production, may not always be exempt from the laws and regulations which must be observed for full-scale farming operations. The expense of applying for and paying for individual permits and licenses to build and operate, to take and use water, and to return the water safely into a natural system, add considerably to the basic capital investment both directly through fees and legal costs and indirectly through project delay.

As a result, the pilot-scale operation in commercial aquaculture, with all its protracted costs, is not looked on as the entity that it is—namely a commitment and positive investment in a decision making process based on a new and increased scale of fair trial and study to prevent unnecessary financial loss of a large investment at a later date. Instead, it has become an expensive and time-consuming hurdle intervening in the process of making a return on investment in the shortest possible time. Consequently, the operators try to over-commit the pilot-scale work and advance into annual production using the facilities and making decisions and judgments on the results which can be biased.

3. Site Limitations

The lack of available land for aquaculture projects, both topographically and/or environmentally suitable, has always been a constraint to the scaling up of aquaculture projects. The logic of locating the pilot-scale project is either to place it adjacent to the site where the previous research has been accomplished, or to put it at a site where the potential for immediate expansion into a farming operation can take place if the work is successful. Either of these good intentions adds the obvious complications to the site selection process and influences the chances of the project to succeed.

Locating the pilot-scale project at a site where expansion is possible is a distinct advantage, but the site selection process and scale of operation are then influenced by the quality and quantity of suitable water necessary for the expanded operation and not the pilot project. Also, the decision on site selection can be influenced by an immediate need to purchase or have an option to purchase the entire area if the pilot project is successful. Consequently, decisions which should be based on the results of the pilot-scale work are being pre-empted as part of the pilot-scale site-selection process.

4. Deficiencies in the Biodata

Much basic research in aquaculture is usually conducted in the laboratory long before consideration of a pilot-scale project. However, the data collected in the interests of the preliminary demonstration and research are not always relevant to the biodata required for scaling up the operations—even to pilot-scale. For example, much of the initial laboratory data are concerned with the biology of the fish or shellfish, namely growth and survival, feed preferences, and daily rations, all under controlled conditions of temperature, salinity, pH, oxygen, and other water quality criteria. Although all these data are important and have a bearing on future daily operations, they are not useful numbers to the engineer and facility designer.

The key data for the designers and engineers are the extremes of the ranges of these parameters, particularly oxygen and ammonia levels, which are tolerated by the fish or shellfish, and when these extremes might occur under set levels of water exchange rates, and at differing densities and biomass of the captive populations. Also important (but hardly available at all) is some knowledge of the behavior and reactions of large populations under differing conditions, particularly in times of stress.

Pilot-scale facilities are often designed on poorly defined biodata as reliable and complete data are not available. As a result, the engineering design can be restrictive and inflexible and can subsequently influence the biological tests unfairly.

5. Lack of Biological Resources

At the laboratory-scale the numbers of individuals which make a worthwhile experiment are comparatively small. At the pilot-scale the logistics are very significant and demanding on the limited resources of natural stocks which are often used for aquaculture experiments, or on the limited resources of a small hatchery. Experiments which are planned to show significant differences with economic meaning for subsequent farming operations have to utilize well-stocked test units. For example, stock density is a key economic factor; therefore it is preferable that experiments are conducted at a wide range of 40, 20, and 5 juveniles per square meter rather than a narrow range of 15, 12, and 9 juveniles per square meter, even though the latter may be the anticipated optimal range. However, to stock a facility at 40 juveniles per square meter in a one-acre pond in triplicate experiments is a significant number (over half a million) of live and healthy young fish, and may not be feasible for limited production hatchery and nursery facilities.

It is also preferable when conducting experiments if fresh stocks of animals can be used at the differing periods within their life cycle anticipated to be important in future farming practices, i.e., sorting or transfer to grow-out, etc. However, because of the limitation of resources of individuals, the same animals are often re-grouped or re-combined at the end of one experiment for future work. As a result, problems which may not be apparent in a first experiment may have a significant bearing on the results of the second; for example, an exposure to stress or hierarchy. Consequently, the lack of biological resources in quantity and quality can be a significant factor in obtaining non-repeatable and unreliable data at the pilot-scale.

6. The Limitations of Experimental Design

Although much of the experimental work in pilot projects is considered to be a practical trial rather than a controlled scientific experiment, the need for replication and flexibility within trials is important. This again makes demands on the number and size of working units required at a pilot facility and on the number of individuals to be utilized. Although to some extent the need for replication in pilot projects has been overcome by repetition of work in successive seasons, this always leaves room for doubt about the results because of the known or unknown differences of the experimental stock each year, the different ambient conditions at the time, and the restrictive limits of that particular facility.

As a result, the decisions to restrict the pilot-scale facility to a certain type and a certain size of working unit again pre-empts decisions that normally follow the pilot-scale phase. Errors in judgment in specifying what constitutes the pilot-scale facility can bias the results of the experimental work and can have significant repercussions on the decisions to go to full-scale production.

Although pilot-scale facilities can be small and modular in design, the use and interpretation of results from small units is limited, and they protract the pilot-scale phase unnecessarily. Operating at this intermediate level would indicate that the technology for that particular species was not in fact ready for true pilot-scale development.

Criteria for Design

All aquaculture facilities have a purpose to promote the efficient transfer and circulation of water throughout in order to provide sufficient oxygen to the captive population and to maintain a suitable environment for life. Well-designed pilot-scale facilities are based on the factual bio-engineering criteria developed by research which meet the behavioral and growth needs of the species.

With the exception of hatcheries and outdoor facilities for salmonid fishes, little engineering development work at the pilot-scale level has gone further than refinements for embankments and improvements to inlet and outlet sluices. As a result, many pilot-scale grow-out facilities have proved to be poor environments for fish and shellfish and have subsequently required additional installations, such as mechanical aeration systems, to enable them to meet the production levels for which they were originally sized.

Biological and the environmental factors that affect the growth of fish or shellfish in captivity, together with their particular behavior, dictate the limits of facility production. Furthermore, production cannot be estimated unless the water resources and drainage of the system are established. These parameters, in turn, are influenced by the dimensions of the pond, the engineering of the water systems, pond management, and, of course, water quality.

Much of the present design work for pilot-scale facilities is based on experiences and facts known to design engineers in hydraulics, soil mechanics, structural materials, and to their ability to interpret and apply information gained from existing facilities. The engineer has some basic biological information by which to reason the design of appropriate facilities. For example, large ponds are more stable environments than small ones and can buffer themselves against sudden changes in water quality, outbreaks of disease, and poor management practices. They often have the disadvantage of difficulty with harvesting. Small ponds or raceways, on the other hand, are easier to maintain and manage, but are more expensive to build and operate and have little to counter an emergency during disease epidemics or environmental changes.

In addition to the importance of depth and surface area to aquatic animals, some consideration must also be made for the growth of other organisms which provide an important dietary component in a pond system. Most of the criteria for establishing supplemental feed populations are related to satisfactory conditions for algal production which is a vital component of the food web in the pond system.

Pilot-scale facilities are also designed and constructed with other factors in mind in addition to the biological needs of the fish. The fish farmer or researcher needs ready access for sampling and harvesting, and also continual daily observation. At these times, it may be necessary to drain and fill the pond rapidly without causing unnecessary stress on the populations of animals contained. This requires special design features in the water delivery system and the outlet gates.

Summary

There are many limitations to the scaling-up of small aquaculture facilities to a pilot-scale level. Probably the most significant is the lack of clear objectives for the pilot project to achieve. A well-defined program of goals and the time frame for each is essential for the facilities to function satisfactorily.

Decisions which determine the siting of the pilot-scale facility or its scale of operation must not be pre-empted by decisions for subsequent enlarged activities. Site selection criteria based on biological related factors for pilot-scale operations, such as water quality and quantity, have preference over more economic related factors such as the limited ownership of land or room for expansion. Decisions to expand to a commercial scale must be based on the practical results of the work at the pilot-scale level and not the anticipated results obtained by theoretical computation.

References

Mitchell, J. R. 1980. Constraints to aquaculture research at the pilot-scale level. EIFAC/80/Symp: E/67. Stavangar, Norway. May 1980.