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Commercial Production of Sturgeon: The Economic Dimensions of Size and Product Mix

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COMMERCIAL PRODUCTION OF STURGEON:
THE ECONOMIC DIMENSIONS OF SIZE AND PRODUCT MIX

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INTRODUCTION

The fishery history of the white sturgeon *(Acipenser transmontanus)* and related sturgeon species dates back to the 19th century in the United States. Prior to the end of the century, the annual sturgeon harvest of the United States was 25 million pounds, but overfishing and the damming of rivers serving as spawning grounds led to a severe decline in sturgeon population. The current commercial catch (where still permitted) is estimated to be less than 5 million pounds annually (McGuire, 1979).

Since the late 1970s, University of California, Davis, researchers have investigated the physiology and growth of white sturgeon in an effort to mitigate this decline in population through enhancement programs and the development of sturgeon aquaculture. This study is part of that effort; its goal is to assess the economic feasibility of the artificial propagation and intensive culture of white sturgeon based on current biological data and aquaculture techniques. While long-run planning by firms frequently centers around consideration of economies of size, the confined production of sturgeon offers a more complex situation; size is just one dimension which must be incorporated into the planning process. Because the sturgeon can be marketed at different stages of growth—newly hatched larvae, 1-month-old fry, 3-month-old fingerlings, or as larger adult fish—the commercial hatchery can become a multi-product firm. The strategy with which the sturgeon are marketed defines the multi-product nature of the firm. Therefore, this study will consider the sturgeon hatchery in its multi-product format and evaluate the various measures of economic performance—cost, profit and rate of return—for such a firm.

To achieve this objective, a quantitative systems model of sturgeon hatchery and growout facilities was developed relying on the major biological and physical input-output relationships reflected in the research by the UC Davis aquacultural facility. Engineering economics techniques were used to establish the systems model.[1]

In addition to data on the economic measures mentioned above, the systems model also provides information on requirements for capital investment and annual operating costs during the start-up and subsequent operation of a facility over a 10-year period. Computer simulation techniques then are applied to the model in order to study the economic outcome of varying management decisions. Figure 1 presents an overview of the modeling process utilized in this study and the information derived therefrom.

This report is divided into three main sections. The first, the Nature of Commercial Sturgeon Production, discusses the technical and economic aspects of intense production of sturgeon. The format of the systems model which will be used in the analysis is also described. The second section, Empirical Estimation of the Model, reports the quantification of the systems model for a base model facility from which the remainder of the analysis is developed. The third section deals with the simulations used to evaluate economically the scale and product mix dimensions of sturgeon production. Finally, the conclusions section considers further implications and possible additional research needs.

THE NATURE OF COMMERCIAL STURGEON PRODUCTION

Sturgeon to date have not been bred successfully in captivity. Therefore, commercial production relies on obtaining broodstock from their natural habitat during the spawning season. Eggs are removed from the females and hand fertilized with the sperm taken from the males. After hatching, the fish are reared to various ages in progressively larger holding tanks.

The primary feature of sturgeon production which distinguishes it from many other livestock or aquacultural operations is its multi-product nature. Fish can be produced to several stages of growth and either marketed as final products at any of these stages or retained as inputs for further production. Thus, when the firm determines at which one or more of the several stages of growout it will market its output and in what amounts, it has defined uniquely its multi-product dimension. We shall refer to this decision as the firm's "marketing strategy." The next step is to designate the size of operation. While other operational dimensions are important in evaluating plant economics (e.g., stocking density of fish per pond or tank), the focus of this study will be on size and marketing strategy.

Plant size may be measured in terms of either input or output capacity. In the case of the sturgeon facility, defining capacity in terms of final product is not as meaningful as a measure in terms of some input capacity because a given single output value might result from more than one marketing strategy. Thus, size of facility is specified as the total number of broodstock handled each spawning season.

[1]See Allen *et al.,* for a comprehensive review of modelling methods and their application in the examination of economic aspects of aquaculture of various organisms.

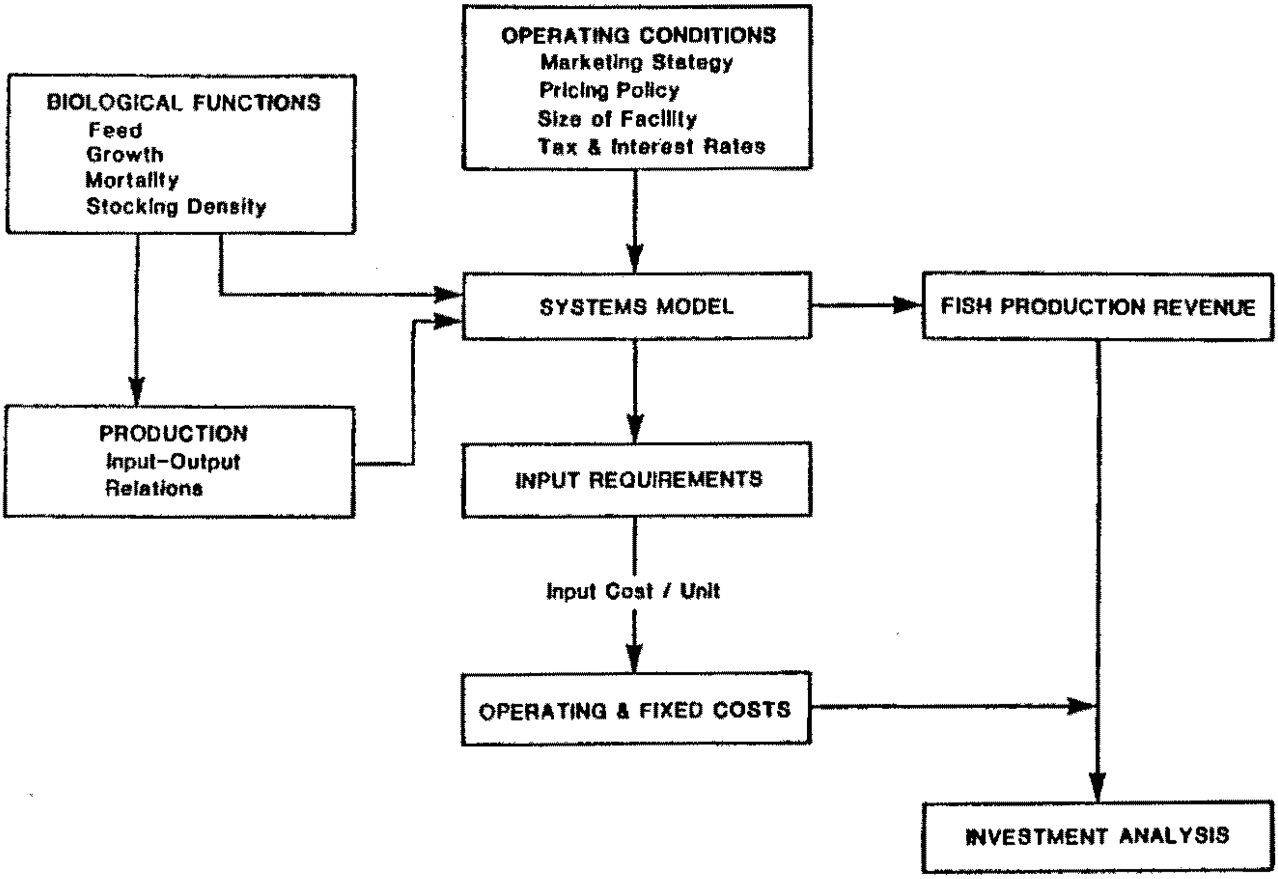

Figure 1. Overview of the modeling process. The biological functions, production input-output relations and operating conditions are the major components of the model. The model subsequently derived provides information on input requirements, costs, production levels, and revenue.

The multi-product characteristic of sturgeon production also creates problems of joint costs and how they should be allocated to the individual products for purposes of cost analysis. Generators, water treatment equipment, and office equipment are examples of such inputs whose use is not particular to any given product. Allocation of such costs when necessary is, of course, arbitrary, but the method of the allocation may itself affect the relative costs and profitability of the various products.

In the analysis which follows, the cost estimates represent points of the long-run cost surface. The effects of short-run variation of output are not considered. When the marketing strategy of the firm changes—even though plant capacity (broodstock numbers) is unchanged—the input requirements including building, holding tanks, and other investment items will also change—hence the long-run nature of the cost points.

The Systems Model

A system is simply a set of integrated elements which together perform some real world process or function. Our system, for example, encompasses the set of hatchery and growout operations required to produce sturgeon of various ages, i.e., it transforms inputs into outputs.

Development of a systems model of sturgeon production in the context of size and market strategy dimensions utilizes three fundamental components: (1) operating procedures and operating conditions, (2) biological functions regarding fish growth and mortality, and (3) input-output relationships.

The operating *procedures* specify the stepwise culture process in a technical sense and directly follow the hatchery and growout techniques developed at UC Davis and a private facility. These procedures define how the brood fish are collected, how the eggs are obtained, fertilized and hatched, and how the newly hatched fish are raised to the various stages of growth. A detailed discussion of these aspects of the production process is presented in Appendix A.

Operating *conditions* characterize the technical and economic environment in which the firm operates. Economic factors include the pricing mechanisms for purchasing inputs and marketing final outputs and certain costs affected by location (e.g., property taxes, utilities, etc.). Technical conditions include the physical input-output relations such as yield of hatchlings from a given spawn. In this sense, the size and marketing strategy dimensions along with the operating procedures and conditions form the specifications which characterize the firm.

The biological functions (see Figure 2) provide the driving mechanism for the systems model by quantifying the physical response of animals to the culture environment specified above. Different functions, based on data from the UC Davis aquaculture program, relate to growth, mortality, feed consumption and stocking densities for different ages of fish. Growth, feed requirements, and mortality are each determined by the interactions of many factors but in this study are expressed as a function of age in months. This approach provides a useful means of tracking these biological components of the model over time. These functions are described in detail in Appendix B.

Whether the operating procedures and the biological functions incorporated in the model represent optimal culture conditions is not known. They do reflect the general efforts at the UC Davis aquaculture facility to maintain fish in an overall healthy state, and are, therefore, specific to the particular culture system employed.

The biological functions provide the means for calculating the physical input-output requirements from which the costs are developed. Given the assumption of *ad libitum* feeding practices, measuring growth of the fish as a function of age is appropriate. Feed requirements then are estimated on the basis of maximum growth for the particular operating procedures applied. Mortality also is a function of age. Growth and maturity coupled with a stocking density relationship for different weights of fish provide the basis for specifying the number of various sizes of holding tanks which in turn sets the stage for developing other input requirements (water, mechanical feeders, utilities, etc.).

The systems model is designed to evaluate various size and product mix combinations in terms of costs and revenues. Cost per fish is calculated for each of the production stages to permit analysis of the effects of changing the plant specifications on relative costs of the individual outputs. From the output of the systems model, the rate of return on investment can be determined.

EMPIRICAL ESTIMATION OF THE MODEL

As indicated earlier, the objective of the study is to analyze the nature of costs, profits and rates of return on investment for sturgeon facilities with differing dimensions of size and marketing strategy. To accomplish this end, the general operating conditions confronting the facility, regardless of size and marketing strategy must be stipulated. Then, a base model for a particular production operation is developed which is subsequently expanded to include the differing dimensions of size and marketing strategy.

Operating Conditions

For any plant size (capacity) specification, the broodstock are assumed to be maintained in the ratio of 60 percent female and 40 percent male. The average female body weight is specified to be 36 kilograms with an average spawn of 9,075 eggs per kilogram of body weight. A fertilization rate of 75 percent and a hatch rate of 55 percent result in a yield of about 135,000 hatchlings per brood female fish.

From these specifications, the mortality function permits calculation of the number of surviving fish at subsequent stages of growout.

As discussed earlier, management decisions in the planning process focus on size, marketing strategy and stocking density. These items all constrain the production process and hence the requirements of inputs. In this analysis, such decisions remain constant from year to year during the 10-year horizon over which operations are modelled.

The model stipulates that the production from a given cohort of fish may be sold at four age categories: Stage I, newly hatched (nonfeeding) larva; Stage II, 1-month-old fry; Stage III, 3-month-old fingerling; and Stage IV, 3 years of age. However, all fish of a given cohort must be sold by the end of the third year of growout.[2] The marketing strategy determines the proportion of surviving product to be sold at each of these selling stages. For the first three selling stages (nonfeeding larva, fry, and fingerling), the proportion of surviving animals sold (P) may range from 0 to 1. In the case of 3-year-old fish, P always equals 1 since all retained fish are sold at the end of three years of growout.

At the end of the first year of operation, the facility will have 1-year-old fish only (provided some newly hatched larvae are retained for growout). At the end of the second year of operation, the facility will have 2-year-old fish

[2]Because the available biological data at the time of this study included fish no greater than three years of age, the production facilities in this study were restrained to handle fish within that age range. As additional data become available, the economic costs and benefits of growing fish to larger weights can be analyzed.

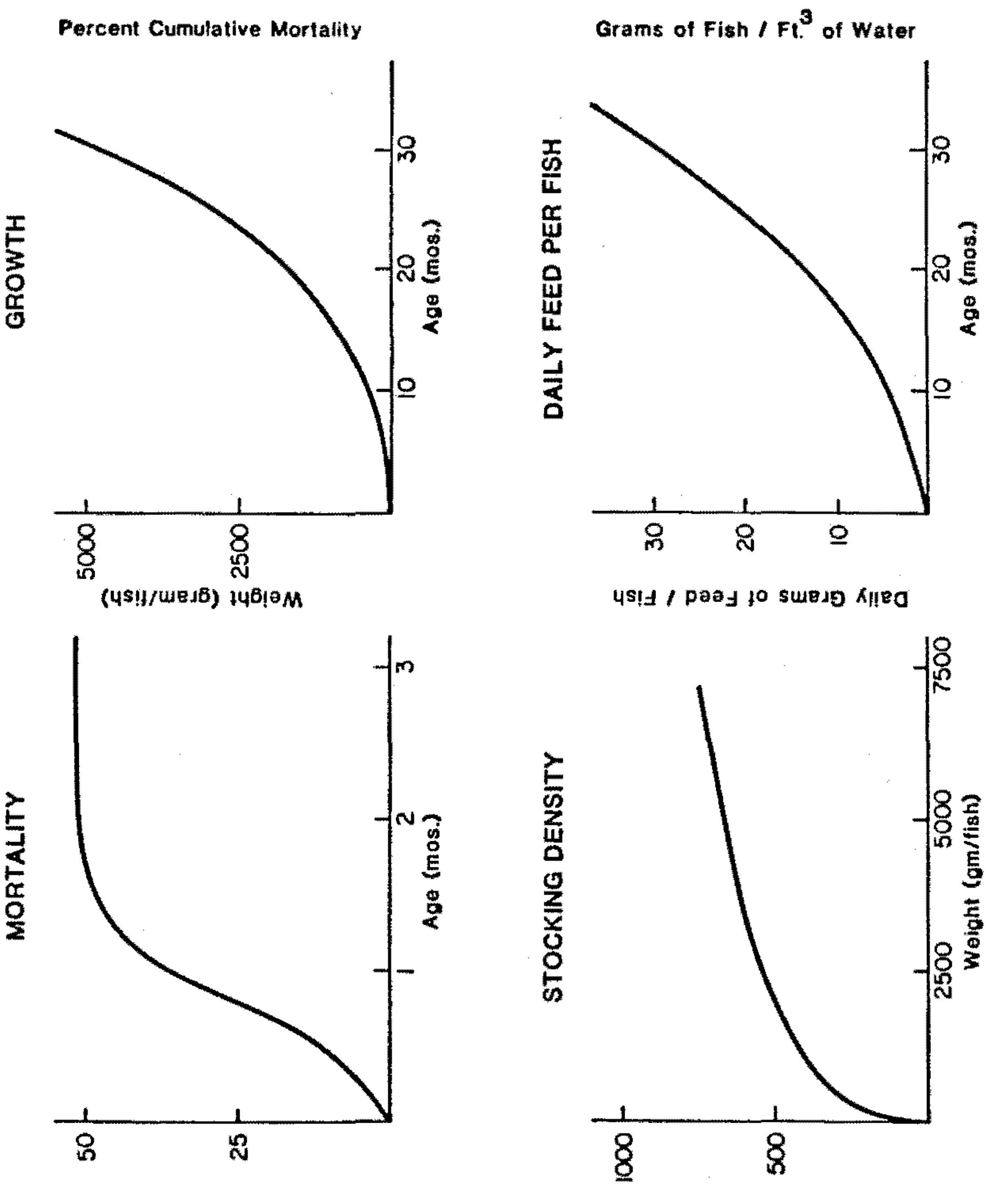

Figure 2. The biological functions describing mortality, growth, stocking density, and daily feed per fish. See Appendix B for the equations.

(provided some fry and fingerlings are retained) and 1-year-old fish resulting from the current year's spawn. By the end of the third year of operation, the facility will have 3-year-old fish ready for sale, 2-year-old fish (from the second year's spawn), and the newest cohort of 1-year-old fish. Since the size of the facility and marketing strategy remain constant, operations in year 3 are replicated during years 4 through 10.

The location of a facility affects the cost of items such as property taxes and utilities. The model incorporates cost conditions appropriate to Davis, California, and uses a state property tax rate of 1 percent and a utility rate comprised of a demand charge of $1.82 per KW per month and $.064 per KWH. Thus, the costs of production for other geographic locations would have to be altered when such cost items differ from those specified here.

The initial start-up and operating costs of the facility may be supported by debt, equity, or some combination of debt and equity financing. Interest payments on debt are tax deductible and hence affect after tax earnings and measures of investment value. The model assumes 100 percent equity financing.

Base Model Facility

Operating conditions were initially defined for a *base model* facility, whose production costs subsequently serve as a point of reference. The base model facility obtains 10 broodstock (six females, four males) per season for spawning purposes.

The base model facility marketing strategy stipulates that 50 percent of all newly hatched larvae is sold immediately. One month later, 50 percent of the surviving fry is sold. An additional two months later, 50 percent of the surviving fingerlings is sold. At the end of three years growout, all remaining fish of a particular cohort are sold. Although actual prices for the different ages of fish typically are variable, the following price schedule was employed here: $.15 per newly hatched larva, $.45 per 1-month-old fry, $1.25 per 3-month-old fingerling, and $4.00 per pound for (whole) 3-year-old fish. This schedule reflects average 1984 prices received at commercial facilities and information available from wholesale distributors. A federal income tax rate of 46 percent and a labor wage rate of $6.00 per hour are used.[3]

Input-Output Relationships

Based on a given number of broodstock, and the hatch and fertilization rates, the growth and mortality functions determine the individual weight and surviving number of fish at various ages. Operating procedures (such as stocking density) and operating conditions built into the model link these biological functions to associated requirements for physical inputs (e.g., tanks, feed, etc.). In the short run, some inputs are available only in fixed supply. Typically, equipment, buildings, and land are fixed inputs. The use of other inputs varies with the production level. In this study, the major variable inputs include feed, labor, and utilities.

The four production stages defined above serve as subsets of the production process for purposes of analyzing input requirements. Thus, for example, production Stage I, hatchery operations, encompasses all activities culminating in the production of hatchlings: fishing for broodstock, spawning of broodstock (i.e., collection of eggs and sperm, and *in vitro* fertilization), and incubation of the fertilized eggs. The other stages include those activities required for production required for production of 1-month fry, 3-month fingerlings, or 3-year fish, respectively.

Equipment requirements specific to each stage of production are determined for a 10-year period of operation. Broodstock fishing operations use a 16-foot, flat bottom boat. Three gill nets are used for fishing for broodstock and are assumed replaced every season. Broodstock are transported back to the facility in a partitioned rectangular, fiberglass fish hauler (304-gallon capacity) which can accommodate two fish. The incubation system has a capacity of 700,000 eggs per incubation; or, 5.6 million eggs per 8-week spawning season (assuming the incubation system operates at capacity each incubation run, and each incubation period is equal to one week). At the beginning of production stage II (hatch to 1-month growout) larval tanks are initially stocked at a constant level of 25,000 larvae per tank.

The semi-moist diet (fed during the first 1½ weeks of feeding) requires storage at 4°C to prevent spoilage. Freezer requirements, sufficient to store enough feed for one spawning season, are calculated assuming each freezer has a capacity of 23 cubic feet, and 50 pounds of feed requires three cubic feet of storage space. During production stages III (1- to 3-month growout) and IV (3-month to 3-year growout), the stocking density function determines the number of fish stocked per tank and hence the required number of tanks. Beginning with production stage III food is dispensed from automatic feeders (2 feeders per tank). The various types of tanks used in the production process have different aeration requirements as determined by the water depth and total water volume per tank (Appendix 1). The aeration systems associated with the different types of tanks are described in Appendix 2.

Buildings consist of prefabricated, corrugated sheet metal pole barns; the roofing for outdoor tanks is similarly constructed, but without walls. Building space requirements reflect the square footage needs of the incubation system(s)

[3]In this study the federal income tax rate is not a function of gross taxable income; instead, it is fixed at the maximum marginal corporate income tax rate. State income taxes are not considered.

and the larval and indoor 12-foot diameter tanks. An additional 2,400 square feet of building space is designated for office, laboratory, and living quarters. Roofing requirements for outdoor tanks are based on the number and areas of outdoor 30-foot diameter tanks to be sheltered (Appendix 4). The land needed by the facility is a conservative estimate and incorporates only the acreage required for buildings and roofing for outdoor tanks.

Joint equipment items are not specific to a particular phase of operations; but rather contribute to all production stages. The emergency generator system must be capable of supporting the entire aeration system in case of power failure; hence its capacity is based on the combined KW requirements of the aeration systems (Appendix 2). The number of wells required is a function of the maximum water requirements of the facility at any given time and the production capacity per well (see Appendix 6a for calculation of well requirements for the base model facility).

The quantities of the variable inputs of labor, utilities, and feed required are also determined for each production stage. Labor requirements for each production stage (as estimated from discussions with operators of private facilities and the UC Davis aquaculture facility) are listed in Appendix 5. Fuel consumed during the fishing expedition is computed on the basis of distance of the facility from the fishing site and hours spent fishing. Truck fuel mileage is assumed to be 15 miles per gallon; one hour of boat operation uses six gallons of fuel.

Electric utility service is used to pump water and to operate the aeration systems and automatic feeders. Total water requirements for a given stage of production are determined on the basis of flow rates per tank, the number of tanks used, and the number of days tanks are occupied. Water requirements for the base model facility are shown in Appendix 3. Given engineering specifications as to well head (total feet water is lifted) and overall efficiency of the well pump, the KWH required to pump the water can be determined (see Appendix 6b). KW requirements for operation of aeration systems are based on manufacturer's specifications (see Appendix 2). Automatic feeders are assumed to operate a total of one hour per 24-hour period and draw 0.88 KW. Feed requirements are determined by the feed function and the number of fish retained at each production stage.

The input requirements and their respective prices define the total expenditures for capital (fixed) investments (i.e., equipment, building, and land) and operating expenses (labor, feed, and utilities). Total annual labor costs are based on a specified hourly wage rate of $6.00 plus an overhead expense (employee benefits and workman's compensation) of 30 percent of wages.

Capital investments give rise to the annual costs of maintenance, insurance, taxes, and depreciation. Annual maintenance costs are set at 0.5 percent of the original cost of equipment. Annual insurance costs for buildings and equipment are estimated according to the schedule in Appendix 7. Property taxes are assessed at 1 percent of the original cost of equipment and buildings. The accelerated cost recovery system (ACRS) of depreciation is used to allocate the costs of equipment and buildings on an annual basis over the 10-year period of operations. Depreciable property may be classified as having a life of 3, 5, 10 or 15 years (see Appendix 8a). Based on the life of an asset, the ACRS determines the recovery percentage for each year of the asset's lifetime (see Appendix 8b). For a given class of asset, the ACRS depreciation schedule may not be constant from one year to the next; consequently, the annual depreciation cost of an asset as determined by the ACRS may not be constant.

Expenditures for capital investments (excluding joint equipment) and operating expenses have been separately specified for each of the four production stages. Because joint equipment items contribute to all phases of production, their cost is apportioned equally among the four production stages.[4]

Model Validation

The purpose of model validation is to determine whether inferences made about the production transformation process incorporated in the model are representative of the actual real world process. Naylor and Finger (1967) consider model specification and validation a multi-stage process which begins with: (1) specification of model components and functional relationships, followed by (2) attempts to validate these components and functional relationships built into the model, and (3) comparisons of "input-output transformations generated by the model to those generated by the real world" (Van Horn, 1971).

There is little empirical data regarding sturgeon production at the present stage of industry development. Thus, statistical comparisons between model and real world input-output data cannot be made. As input-output data from commercial facilities become available, such comparisons can be made and validation can proceed further. Until such time, validity of the present systems model is based on the credibility of the model as determined by the reasonableness of the components (i.e., operating procedures and biological functions) which drive the model internally.

The operating procedures and biological functions built into this model were based on information from researchers and operators of private facilities. Hence, these model components are "reasonable" in that they reflect current culture practices and the associated biological responses of animals.

[4]This is a reasonable assumption for office and laboratory equipment, small tools, and trucks. In future studies it would be more realistic to apportion the cost of the emergency generator, wells, and stripping towers among the four production stages according to the proportion of equipment capacity required by a particular stage of production.

Model Output and Measures of Performance

The total cost associated *with a given stage of production* is determined annually for years 1 through 10 of operations and consists of the annual cost of: (1) depreciation of equipment and buildings, (2) property taxes on land, equipment, and buildings, (3) insurance for buildings and equipment, (4) utilities for pumping water and operation of the aeration systems and automatic feeders, (5) feed, (6) labor, and (7) maintenance. Items 1 through 3 are fixed costs, 4 through 7 are variable costs. Maintenance has both fixed and variable components; some maintenance is required even if buildings and equipment are unused. However, usage of these items adds significantly to the required upkeep. Therefore, in this study maintenance has been treated as a variable cost item. In addition to the preceding items, total cost for production stage I also includes the cost of fuel for travel to and from the fishing site and operation of the boat, and the cost of pituitary extract required for induction of gonadal maturation.

The average total cost per unit of output (ATC) for the production of hatchlings, fry, fingerlings, or 3-year-old fish is also determined annually for years 1 through 10 of operations. ATC for a particular production stage in year i is calculated by dividing the total annual cost in year i for that production stage by the number of animals retained by the facility which survive to the end of that stage. The average variable cost (AVC) is similarly calculated for each stage produced, but incorporates only the variable input costs of feed, labor, utilities, and maintenance.

In the growout process, outputs from earlier stages of production serve as inputs for later stages. In calculating *average costs* per unit for each stage, the production costs of those outputs serving as inputs must be incorporated into the production costs of subsequent outputs. If the proportion of product sold at a particular production stage (as specified by the marketing strategy) is P, then the proportion of that stage's total production costs to be passed along to the next stage of production is 1 - P.

Production costs, *per se*, do not determine the economic feasibility of the sturgeon culture system. Information on revenue or product demand in the form of prices obtainable for hatchlings, fry, fingerlings, and 3-year-old fish is also needed. Given a price schedule and marketing strategy, the revenue generated from each production stage can be calculated and total annual revenue for the facility obtained. For a facility, net income (or loss) before taxes in year i is:

$$\text{Net income}_i = \text{Revenue}_i - \text{Equipment depreciation}_i - \text{Building depreciation}_i - \text{Property taxes}_i - \text{Maintenance}_i - \text{Insurance}_i - \text{Operating costs}_i$$

where revenue and all cost figures are the annual totals for the facility derived from all four production stages. Operating cost is the total variable cost in year i for labor, fuel, pituitary extract, feed, utilities (for pumping water and operating the aeration systems and automatic feeders), and maintenance.

Federal income taxes are assessed on net income earned by the facility; in the case of a negative net income, or net operating loss (NOL) there is no income tax liability. A NOL also can be used to reduce taxable income in other tax years. It may be carried back to an earlier tax year (up to three years before the NOL year) or carried forward up to 15 years after the NOL year. Property which is depreciated under the ACRS is eligible for an investment tax credit of 10 precent of the investment. The total annual credit allowable is assumed to be limited to the income tax liability of that year. As with a NOL, investment tax credits may also be carried backward (up to three years) or forward (up to 15 years) to reduce the tax liability in other years. Thus, federal income tax is assessed on net income after adjustments for any NOL. The resultant income tax liability is then reduced by any investment tax credits (up to the amount of the tax liability itself) in order to determine the federal income tax liability for that year.

In order to evaluate further the economic performance of a sturgeon culture system, the cost and revenue information is used to measure the potential internal rate of return of the investment.

The rate of return, the measure used in this study, is the discount (interest) rate that equates the present value of cash inflows with the present value of cash outflows (Bierman and Smidt, 1975; Osteryoung, 1979; Clark, Hindelang, and Pritchard, 1979). The rate of return of an investment is determined iteratively when the annual flows of cash outlay and income are not uniform. The model assumes cash inflows occur at the end of each annual period, while cash outflows occur at the beginning. *A different timing of inflows and/or outflows will alter the rate of return values.*

In this study, expenditures for capital investments represent cash outflows; cash inflow is represented by annual net income after tax, but with annual charges for equipment and building depreciation added back. There are 10 annual time periods.

BASE MODEL PRODUCTION, COSTS AND REVENUES

To reflect the dynamic nature of the sturgeon production, the systems model evaluates the operation every 10 days for fish up to six months of age and every 20 days thereafter. The biological functions are evaluated for the midpoint of the time intervals and these values form the basis for extrapolating feed requirements, etc., for the rest of the time period.

The biological output of the base model facility resulting from one year's spawning activity is summarized in Table 1. Each female yields 326,700 eggs, of which 245,025 (75 percent) are successfully fertilized *in vitro*; of these, 134,763 (55 percent) successfully hatch. Thus, six females produce 808,582 hatchlings, 50 percent of which are sold immediately. The 404,291 hatchlings retained weigh a total of 6.46 kg. The mortality function determines the cumulative proportion of the *original* number of hatchlings (in this case the 404,291 hatchlings retained) which have died at a given age. For example, cumulative mortality at 1 month of age is approximately 37 percent; hence 254,007 1-month-old fry survive from the original retained hatchlings population of 404,291. At the age of 1 month, the base model sells 50 percent of the 254,007 surviving fry (i.e., 127,004) and is left with a total of 24.13 kg production (0.19 gram/fry x 127,004 fry x 1 kg/1000 grams). The following equation is used to determine the proportion of the population at time t which dies during the interval from t to t+N (where N is some positive number of months):

$$\text{Proportion of population at time t dying during the time interval from t to t+N} = \frac{CM_{t+N} - CM_t}{1 - CM_t}$$

Table 1

Base Model Facility Production[a] (Per Cohort of Fish)

Total Number of Broodstock: 10
Marketing Strategy: 50 percent

Age	Body Weight (grams/fish)	Number Produced	Number Sold	Production[b] (kg)
Hatchling	0.016[c]	808,582	404,291	6.46
1 month	0.19	254,007	127,004	24.13
3 months	19.08	95,021	47,511	906.49
6 months	102.60	47,502	0	4,873.59
12 months	537.32	47,502	0	25,523.98
18 months	1,415.41	47,502	0	67,234.97
24 months	2,814.08	47,502	0	133,674.59
30 months	4,795.52	47,502	0	227,796.73
36 months	7,412.82	47,502	47,502	352,124.02

[a]For all stages after hatch, the number produced takes into account mortality and any previous production sold.
[b]Production retained for continued culture.
[c]Based on mean weight of 12 larvae at hatch (Beer, 1981).

where CM is the cumulative mortality as determined by the mortality function. The numerator represents the proportion of the original population which dies during the time interval from t to t+N. The denominator is the proportion of the original population alive at time t.

During the growout period from one to three months of age, approximately 74.82 percent of the retained 1-month-old fry (based on the preceding equation) survive to the age of three months, resulting in 95,021 fingerlings. After selling 50 percent of the fingerlings, 47,510 are retained for continued growout to three years of age, at which time all are sold. Mortality is small between the ages of three and six months (about 0.02 percent), and becomes insignificant from six months to three years of age. The 906.49 kg of fingerlings retained will yield 352,124.02 kg of 3-year-old fish.

Capital Investments and Operating Cost

The type, amount required, and total cost of equipment specific to each production stage over the 10-year period are presented in Table 2. Table 3 lists similar information for the joint equipment items which are not specific to any one production stage. Land and building requirements for each production stage are found in Table 4 (see Appendix 4). Fish are raised indoors up to the age of 6 months. At 6 months of age, fish are transferred to the outdoor tanks which are sheltered by roofing. Essentially all capital investment in equipment, buildings, and land is made during the first three years of operation (as shown in Table 5). The $1,500 expenditure for fishing equipment in years 2-10 represents the annual replacement cost of fishing nets. The total investment cost of equipment (including fishing nets) and buildings is converted into annual cost figures for years 1 through 10 of operations by the ACRS method of depreciation. The annual depreciation costs for equipment and buildings are listed in Tables 6 and 7.

Operating costs of the variable inputs are shown for each production stage in Table 8. In the present systems model, the production of a facility is constrained by size (capacity) and marketing strategy. During the 10-year period over which operations are modelled, these two characteristics of the facility are assumed to remain constant. Hence production from each year's spawning activities is identical to that described in Table 1. As a result, annual operating costs are constant after the hatchery reaches full operation in the third year.

Production Costs

The annual average total costs (ATC) per fish for the production stages of hatch, fry, fingerling, and 3-year-old fish are summarized in Table 9a. Over the 10-year horizon, annual ATC decreases as equipment and buildings become fully depreciated. In contrast, the average variable costs (AVC) per unit for the four production stages remain constant through year 10 at the values shown in Table 9b. In Table 10 the variable costs of labor, utilities, and feed per fish for each production stage are separately identified. For 3-year-old fish (weighing about 7.25 kg) these costs can be represented in dollars per kg (of whole fish): (1) labor cost=$.040 per kg, (2) utilities cost=$1.78 per kg, and (3) feed cost=$1.91 per kg. The sum of the variable costs of labor, utilities, and feed is slightly less than the AVC values listed in Table 9b because the latter also include the costs of hormone injections and fuel used by the truck and boat in broodstock fishing and maintenance.

Total annual production costs for the base model facility are listed in Table 11. The total variable cost increases over years 1 through 3 because the facility does not operate at full capacity until the third year. In the first year, the total variable cost of $120,509 represents the cost of variable inputs required to cultivate only one cohort of fish to one year of age. In the second year of operation, total variable cost increases to $483,893, and includes the variable cost of raising a second cohort of fish to one year of age (i.e., production from the current year's spawn) plus the variable costs of growout from one to two years of age (for fish resulting from the previous year's spawn). The total variable cost of $1,360,910 in the third year of operations includes the variable costs of culture for three cohorts of fish, each at a different phase of growout. At the end of the third year, facility operations reach a steady state.

Revenue, Income and Investment Analysis

Table 12 presents the revenue associated with each stage of production under the base facility marketing strategy. Total annual revenue over a 10-year horizon is shown in Table 13. Annual revenue of $177,184 occurs in the first and second year of operations and results from the sale of hatch, fry, and fingerlings only in both years. At the end of the third year of operations 3-year-old fish are sold for the first time. Thus annual revenue increases to $3,282,353 in the third year and remains at this level for subsequent years. Annual cost deductions from revenue result in net losses for the first two years of operation and positive net income (before taxes) thereafter. As indicated in Table 13, no income tax is paid by the base model facility until the sixth year of operation.

Table 14 summarizes the cash inflows and outflows of the base model facility over 10 years of operation. A rate of return of 1.26 percent is associated with the base model facility. While the rate of return for the base model plant is small, the base model facility is an arbitrarily selected point of reference and is not necessarily an optimal point of operation as will be seen later.

Table 2

Equipment Requirements

Total Number of Broodstock: 10
Marketing Strategy: 50 percent

Equipment	Number Required for Years 1-10	Total Cost (dollars)
Production Stage I		
Boat	1	16,000
Fishing nets	30	15,000
Fish hauler	1	1,100
Brood tanks	4	6,380
Incubation system	1	3,600
Aeration system	1	1,972
Total		44,052
Production Stage II		
Larval tanks	9	4,050
Freezer	1	600
Aeration system	1	1,622
Total		6,272
Production Stage III		
12-foot diameter tanks	135	131,625
Automatic feeders	270	93,150
Aeration system	17	35,003
Total		259,778
Production Stage IV		
12-foot diameter tanks	134	130,650
30-foot diameter tanks	451	2,255,000
Automatic feeders	1,170	403,650
Aeration system (12-foot tanks)	17	35,003
Aeration system (30-foot tanks)	113	265,889
Total		3,090,192

Table 3

Joint Equipment Requirements

Total Number of Broodstock: 10
Marketing Strategy: 50 percent

Joint Equipment	Number Required for Years 1-10	Total Cost (dollars)
Emergency generator	1	72,180
Wells	10	646,120
Stripping towers	10	40,000
Office and laboratory equipment		10,000
Small tools		2,000
Trucks	2	22,500
Total		792,800

Table 4

Land and Building Requirements

Total Number of Broodstock: 10
Marketing Strategy: 50 percent

Production Period	Land			Building and Roofing		
	Acres Required	Total Cost	Annual Tax	Square Feet Required	Total Cost	Annual Tax
		---------dollars--------			---------dollars--------	
Hatch production	0.02	69.02	1	1,002	25,050	251
Hatch to 1 month growout	0.02	61.99	1	900	22,500	225
1 to 3 month growout	0.77	2,324.70	23	33,750	843,750	8,438
3 month to 1 year growout	5.24	15,714.97	157	163,350	1,497,987	14,980
1 to 2 year growout	5.84	17,523.07	175	169,600	856,162	8,562
2 to 3 year growout	14.55	43,642.37	436	422,400	2,132,328	21,323
Office and lab building	0.07	206.64	2	2,400	139,872	1,399
Total	26.51	79,546.12[a]	795	793,402	5,517,649	55,178

[a]Sum of column may not equal total because of rounding.

Table 5

Annual Investment

Total Number of Broodstock: 10
Marketing Strategy: 50 percent

Item	Year of Operation									
	1	2	3	4	5	6	7	8	9	10
	dollars									
Fishing equipment	18,600	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500
Incubation system	3,600	0	0	0	0	0	0	0	0	0
Brood tanks	6,380	0	0	0	0	0	0	0	0	0
Larval tanks	4,050	0	0	0	0	0	0	0	0	0
12-foot tanks	262,275	0	0	0	0	0	0	0	0	0
30-foot tanks	405,000	530,000	1,320,000	0	0	0	0	0	0	0
Automatic feeders	241,500	73,140	182,160	0	0	0	0	0	0	0
Aeration systems	123,013	61,178	155,298	0	0	0	0	0	0	0
Emergency generator	72,180	0	0	0	0	0	0	0	0	0
Freezer	600	0	0	0	0	0	0	0	0	0
Wells	646,120	0	0	0	0	0	0	0	0	0
Stripping towers	40,000	0	0	0	0	0	0	0	0	0
Office and lab equipment	10,000	0	0	0	0	0	0	0	0	0
Tools	2,000	0	0	0	0	0	0	0	0	0
Trucks (2)	22,500	0	0	0	0	0	0	0	0	0
Land	79,546	0	0	0	0	0	0	0	0	0
Buildings	2,529,159	856,162	2,132,328	0	0	0	0	0	0	0
Total Investment	4,466,523	1,521,980	3,791,286	1,500	1,500	1,500	1,500	1,500	1,500	1,500

Table 6

Annual Equipment Depreciation Costs

Total Number of Broodstock: 10
Marketing Strategy: 50 percent

Equipment	Year of Operation 1	2	3	4	5	6	7	8	9	10
	dollars									
Production Stage I										
Boat	2,280	3,344	3,192	3,192	3,192	0	0	0	0	0
Fishing nets	375	570	555	375	570	555	375	570	555	375
Fish hauler	157	230	219	219	219	0	0	0	0	0
Brood tanks	909	1,333	1,273	1,273	1,273	0	0	0	0	0
Incubation system	513	752	718	718	718	0	0	0	0	0
Aeration system	296	434	414	414	414	0	0	0	0	0
Building	2,505	2,756	2,255	2,004	1,754	1,503	1,503	1,503	1,503	1,253
Production Stage II										
Larval tanks	576	845	807	807	807	0	0	0	0	0
Freezer	86	125	120	120	120	0	0	0	0	0
Aeration system	243	357	341	341	341	0	0	0	0	0
Building	2,250	2,475	2,025	1,800	1,575	1,350	1,350	1,350	1,350	1,125
Production Stage III										
Tanks	18,752	27,502	26,252	26,252	26,252	0	0	0	0	0
Automatic feeders	13,284	19,483	18,598	18,598	18,598	0	0	0	0	0
Aeration system	5,250	7,701	7,351	7,351	7,351	0	0	0	0	0
Building	84,375	92,813	75,938	67,500	59,063	50,625	50,625	50,625	50,625	42,188
Production Stage IV										
Tanks	76,325	187,468	405,725	488,470	475,930	369,075	263,340	0	0	0
Automatic feeders	21,156	41,459	70,894	82,321	80,590	50,971	36,369	0	0	0
Aeration system	12,662	27,748	54,481	64,740	63,187	45,460	32,613	0	0	0
Building	150,050	166,520	140,012	126,349	111,242	95,099	93,497	89,505	89,505	74,588
Total	392,044	583,915	811,170	892,844	853,196	614,638	479,672	143,553	143,538	119,529

Table 7

Annual Joint Equipment Depreciation Costs

Total Number of Broodstock: 10
Marketing Strategy: 50 percent

Joint Equipment	Year of Operation 1	2	3	4	5	6	7	8	9	10
	dollars									
Emergency generator	10,286	15,086	14,400	14,400	14,400	0	0	0	0	0
Wells	61,381	67,520	55,243	49,105	42,967	36,829	36,829	36,829	36,829	30,691
Stripping towers	3,800	4,180	3,420	3,040	2,660	2,280	2,280	2,280	2,280	1,900
Office and lab building	13,987	15,386	12,588	11,190	9,791	8,392	8,392	8,392	8,392	6,994
Office and lab equipment	1,425	2,090	1,995	1,995	1,995	0	0	0	0	0
Small tools	285	418	399	399	399	0	0	0	0	0
Trucks (2)	5,625	8,550	8,325	0	0	0	0	0	0	0
Total	96,789	113,230	96,370	80,129	72,212	47,501	47,501	47,501	47,501	39,585

Table 8

Annual Operating Costs

Total Number of Broodstock: 10
Marketing Strategy: 50 percent

Growout Period	Annual Operating cost (dollars)
Hatch production	
Fishing labor[a]	864
Spawning labor[a]	324
Fishing fuel	269
Pituitary extract	370
Water pumping	159
Water aeration	275
Maintenance	220
Total	2,481
Hatch to 1 month growout	
Larval labor[a]	7,392
Larval feed	259
Water pumping	182
Water aeration	1,566
Maintenance	31
Total	9,430
1 to 3 month growout	
Fry labor[a]	2,430
Fry feed	1,120
Water pumping	2,359
Water aeration	1,856
Autofeeder operation	393
Maintenance	1,299
Total	9,457
3 month to 1 year growout	
Finger labor[a]	3,870
Finger feed	29,095
Water pumping	26,493
Water aeration	28,173
Autofeeder operation	3,205
Maintenance	3,842
Total	94,678
1 to 2 year growout	
Labor[a]	1,908
Feed	183,553
Water pumping	84,020
Water aeration	84,569
Autofeeder operation	5,440
Maintenance	3,322
Total	362,812
2 to 3 year growout	
Labor[a]	4,752
Feed	462,609
Water pumping	193,789
Water aeration	193,607
Autofeeder operation	12,548
Maintenance	8,287
Total	875,592

[a]Excludes 30 percent overhead assessment for benefits.

Table 9a

Average Total Cost of Production Per Fish

Total Number of Broodstock: 10
Marketing Strategy: 50 percent

Production Stage	Year of Operation									
	1	2	3	4	5	6	7	8	9	10
	Average Total Cost Per Fish ---dollars---									
Hatchling	0.047	0.055	0.049	0.043	0.041	0.026	0.025	0.026	0.026	0.023
Fry	0.234	0.266	0.237	0.211	0.199	0.144	0.144	0.144	0.144	0.131
Fingerling	2.266	2.624	2.338	2.172	2.045	1.269	1.269	1.269	1.269	1.142
3 year old fish			46.435	51.239	49.596	49.120	48.669	33.892	33.892	33.878

Table 9b

Average Variable Cost of Production Per Fish

Total Number of Broodstock: 10
Marketing Strategy: 50 percent

Stage	Average Variable Cost Per Fish (dollars)
Hatchling	0.003
Fry	0.042
Fingerling	0.156
3 year old fish	28.02

Table 10

Variable Cost Per Fish

Total Number of Broodstock: 10
Marketing Strategy: 50 percent

Production Stage	Labor	Utilities	Feed
		$/Unit of Production	
Hatchling	0.001	0.001	—
Fry	0.031	0.008	0.001
Fingerling	0.067	0.055	0.013
3 year old fish	0.289	13.24	14.23

Table 11

Fixed and Variable Costs of Production

Total Number of Broodstock: 10
Marketing Strategy: 50 percent

	Year of Operation									
	1	2	3	4	5	6	7	8	9	10
FIXED COSTS										
Equipment depr.	268,138	455,644	683,428	762,577	741,982	459,710	339,193	39,679	39,664	32,966
Building depr.	253,167	279,949	232,818	208,843	183,424	156,970	155,367	151,375	151,375	126,146
Taxes	44,800	60,004	97,902	97,902	97,902	97,902	97,902	97,902	97,902	97,902
Insurance	26,723	35,760	58,269	58,269	58,269	58,269	58,269	58,269	58,269	58,269
Total fixed cost	592,828	831,357	1,072,417	1,127,591	1,081,577	772,851	650,731	347,225	347,210	315,283
VARIABLE COSTS										
Maintenance	5,393	8,714	17,001	17,001	17,001	17,001	17,001	17,001	17,001	17,001
Labor and overhead	19,344	21,824	28,002	28,002	28,002	28,002	28,002	28,002	28,002	28,002
Fishing fuel	269	269	269	269	269	269	269	269	269	269
Pituitary extract	370	370	370	370	370	370	370	370	370	370
Feed	30,474	214,027	676,635	676,635	676,635	676,635	676,635	676,635	676,635	676,635
Utilities										
Water pumping	29,192	113,212	307,001	307,001	307,001	307,001	307,001	307,001	307,001	307,001
Water aeration	31,870	116,439	310,046	310,046	310,046	310,046	310,046	310,046	310,046	310,046
Automatic feeders	3,597	9,038	21,586	21,586	21,586	21,586	21,586	21,586	21,586	21,586
Total variable cost	120,509	483,893	1,360,910	1,360,910	1,360,910	1,360,910	1,360,910	1,360,910	1,360,910	1,360,910
Total annual cost	713,337	1,315,250	2,433,327	2,488,501	2,442,487	2,133,761	2,011,641	1,708,135	1,708,120	1,676,193

Table 12

Annual Production, Sales and Revenues at Maturity

Total Number of Broodstock: 10
Marketing Strategy: percent hatch sold = 50 at $.15 each
percent fry sold = 50 at $.45 each
percent fingerlings sold = 50 at $1.25 each
percent 3 year old fish sold = 100 at $4.00 per pound

Production Stage	Number Produced	Number Sold	Revenue (dollars)
Hatchling	808,582	404,291	60,644
Fry	254,007	127,004	57,152
Fingerling	95,021	47,511	59,389
3 year old fish	47,502	47,502	3,105,168

SIMULATION EXPERIMENTS

The base model analysis provides a starting point for study of the effect on measures of economic performance of changes in the planning variables specified for the base model. Simulation experiments permit the alteration of the decision variables of the base model facility in order to draw inferences about the relationships between the altered variable(s) and the system's performance.

Various types of simulation experiments are possible; however, the ones presented here focus on the effects of changes in plant capacity and marketing strategies. There is little doubt that the management decision on stocking density has an important effect on costs of production. However, biological data on the interactions between stocking density and growth and mortality rates are not available; therefore, this experiment was omitted.

In addition to the plant capacity of 10 broodstock used in the base model, the process was also simulated using size levels of 5, 15 and 20 broodstock. These changes were also considered in the context of different marketing strategies or product mixes. The base model facility sells 50 percent of remaining production from a given cohort of fish at each of the three initial stages of growout and all remaining fish at the end of three years. Four alternative marketing strategies were examined for each of the four plant sizes: marketing 10 percent, 25 percent, 75 percent and 90 percent of remaining production at each selling stage (with all remaining fish sold at the end of three years' growout).

Results of simulations varying only the plant capacity (holding marketing strategy constant) will be reported first, followed by the results of the experiments varying only marketing strategy while holding size at the base model level. Finally, the results of varying both dimensions will be discussed.

For the first two discussions, the ATC per unit of production of the base model facility serves as the performance measure against which the outputs from simulation experiments are compared.[5] Rather than replicate the individual 10-year format of costs shown for the base model in Table 9a for each simulation experiment, we have presented in Table 15 the 10-year simple averages of the ATC for the various experiments.

[5]Discussion of comparative rates of return will be deferred until the final sets of simulations are presented.

Table 13

Annual Net Loss or Income

Total Number of Broodstock: 10
Marketing Strategy: 50 percent

	Year of Operation									
	1	2	3	4	5	6	7	8	9	10
Revenue	177,184	177,184	3,282,353	3,282,353	3,282,353	3,282,353	3,282,353	3,282,353	3,282,353	3,282,353
Total annual cost	713,335	1,315,250	2,433,327	2,488,501	2,442,487	2,133,761	2,011,641	1,708,135	1,708,120	1,676,193
Net loss or income	-536,151	-1,138,066	849,026	793,852	839,866	1,148,592	1,270,712	1,574,218	1,574,233	1,606,160
Income tax	0	0	0	0	0	482,829	584,438	724,050	724,057	73,874
Net income after tax	-536,151	-1,138,066	849,026	793,852	839,866	665,763	686,275	850,168	850,176	867,416

Table 14

Cash Inflow and Outflow for the Base Model Facility

Number of Broodstock: 10
Marketing Strategy: 50 percent

Item	Year of Operation									
	1	2	3	4	5	6	7	8	9	10
	dollars									
Net income after tax	(536,151)	(1,138,066)	849,026	793,852	839,866	665,763	686,275	850,168	850,176	867,416
Equipment depreciation	268,138	455,644	683,428	762,577	741,982	459,710	339,193	39,674	39,664	32,966
Building depreciation	253,167	279,949	232,818	208,843	183,424	156,970	155,367	151,375	151,375	126,146
Cash inflow	(14,840)	(402,473)	1,765,272	1,765,272	1,765,272	1,282,443	1,180,835	1,041,222	1,041,215	1,026,528
Cash outflow[a]	4,466,523	1,521,980	3,791,286	1,500	1,500	1,500	1,500	1,500	1,500	1,500

[a]See Table 5 for detailed presentation of investment costs.

Economies of Size

Given the 50 percent marketing strategy of the base model, changes in facility capacity result in equally proportionate changes in production and revenue. (See Appendix 9a-c for production levels of the various sizes of facilities.)

The effect of changes in capacity (i.e., the number of broodstock handled each spawn season) on ATC is shown in the first section of Table 15. As illustrated in Figures 3 and 4, the production costs of hatch, fry, fingerling and 3-year-old fish exhibit economies of size. The long-run average cost curves in Figures 3 and 4 were constructed from the average ATC values in Table 15. For the stages of hatch, fry and fingerling, the ATC per unit of production decreases as facility capacity increases from 5 to 20 broodstock. The ATC per 3-year-old fish decreases over a narrower range from 5 to 15 broodstock capacity. After a capacity of 15 broodstock, there is no apparent reduction in ATC.

The proportionate reduction in ATC, in response to increases in capacity of the facility, is greatest for the production of hatchlings, followed by fry, fingerlings, and 3-year-old fish. When the smallest facility (5 broodstock capacity) is compared with the largest (20 broodstock capacity), there is on average a 37.5 percent difference in the ATC per hatchling, a 26.8 percent difference in the ATC per fry, and differences of 8 percent and 0.3 percent in the ATC per fingerling and 3-year-old fish respectively.[6]

Cost per Hatchling

The production of hatchlings (i.e., broodstock fishing, spawning activities, and incubation) exhibits the greatest economies of size mainly because increased production requires little additional equipment (Appendix 9d-f). The number of broodstock holding tanks increases proportionately, but no new aeration systems, fishing equipment or incubation systems are required as capacity increases from 5 to 20 broodstock. Additional broodstock tanks result in increased building square footage requirements; however, since increased production does not require further square footage for additional incubation systems, there is a less-than-proportionate increase in building cost (and, therefore, property taxes, insurance, and maintenance) for hatchery operations when production is increased (Appendix 9g-i).

Expenditures for some joint equipment items such as office and laboratory equipment, small tools and trucks remain constant regardless of production level; however, the costs of the emergency generator, wells, and nitrogen stripping towers are influenced by production levels. Changes in the cost of joint equipment which accompany changes in production level (Appendix 9j-l) reflect the combined changes in requirements for all four stages of production. Since the total cost of joint equipment is equally apportioned among the four production stages, the economies in joint equipment costs are shared equally among the four stages. Hence one-quarter of these cost savings are attributed to hatchery operations.[7]

Cost per Fry

As was the case with hatchery operations, economies of size in the production of fry (i.e., hatch to 1-month growout) are largely the result of more intensive and better utilization of the capacity of existing equipment. This is apparent from comparison of the equipment requirements (for hatch to 1-month growout) listed in Table 2 with those listed in Appendix 9d-f. The model assumes spawning activities can be carried out any time during an 8-week period (i.e., the months of March and April). Hatchlings are maintained in larval tanks for a 1-month period, at the end of which they are transferred to a 12-foot diameter tank. Thus a larval tank can be used more than once during an 8-week spawning period. This is why (despite a constant stocking level of 25,000 hatchlings per larval tank) the number of larval tanks required increases less than proportionately as production expands. Similarly, the additional building square footage required to accommodate these larger number of larval tanks is a source of economies since it too increases less than proportionately with increased production (Appendix 9g-i). Only one freezer and one aeration system are required by the four different size facilities.

Cost per Fingerling

Economies of size associated with the production of 3-month-old fingerlings is greatly diminished compared to the economies realized in hatchery operations and growout to one month of age. This results primarily because the requirements for 12-foot diameter tanks and automatic feeders increase more than proportionately as production expands (Appendix 9d-f). Because equipment is purchased in discrete units with a given capacity per unit of input, increases in production levels can be associated with greater-than-proportionate increases in input requirements. The 12-foot diameter tanks are housed indoors; thus there are also more-than-proportionate increases in building requirements as production increases. A capacity expansion from 5 to 10 broodstock is associated with a proportionate increase in aeration system requirements for 12-foot diameter tanks; some cost savings (in aeration systems) occur when capacity expands from 10 to 15 and from 15 to 20 broodstock.

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[6] These percentages were calculated using the values of ATC in Table 15. For example, the 26.8 percent difference in ATC per fry is calculated as: (\$.228 - \$.167)/\$.228.

[7] Some economies undoubtedly arise simply as a result of the means by which joint costs are allocated. Any such allocation procedure is admittedly arbitrary.

Table 15

Average Total Costs Per Fish of Producing Sturgeon to Various Stages of Growout[a]

Item	Average Total Cost for Production Stage: I Hatchling	II Fry	III Fingerling	IV 3-year-old fish
1. Size or broodstock capacity				
5	.048	.228	1.87	43.42
10 (Base Model)	.036	.185	1.77	43.34
15	.032	.172	1.73	43.31
20	.030	.167	1.72	43.31
2. Marketing Strategy (percent sold)				
Sell 10	.131	.467	2.31	43.78
25	.083	.332	2.06	43.56
50 (Base Model)	.036	.185	1.77	43.34
75	.019	.135	1.75	43.24
90	.016	.178	2.65	39.52

[a]These figures are averages of 10 years of hatchery operations.

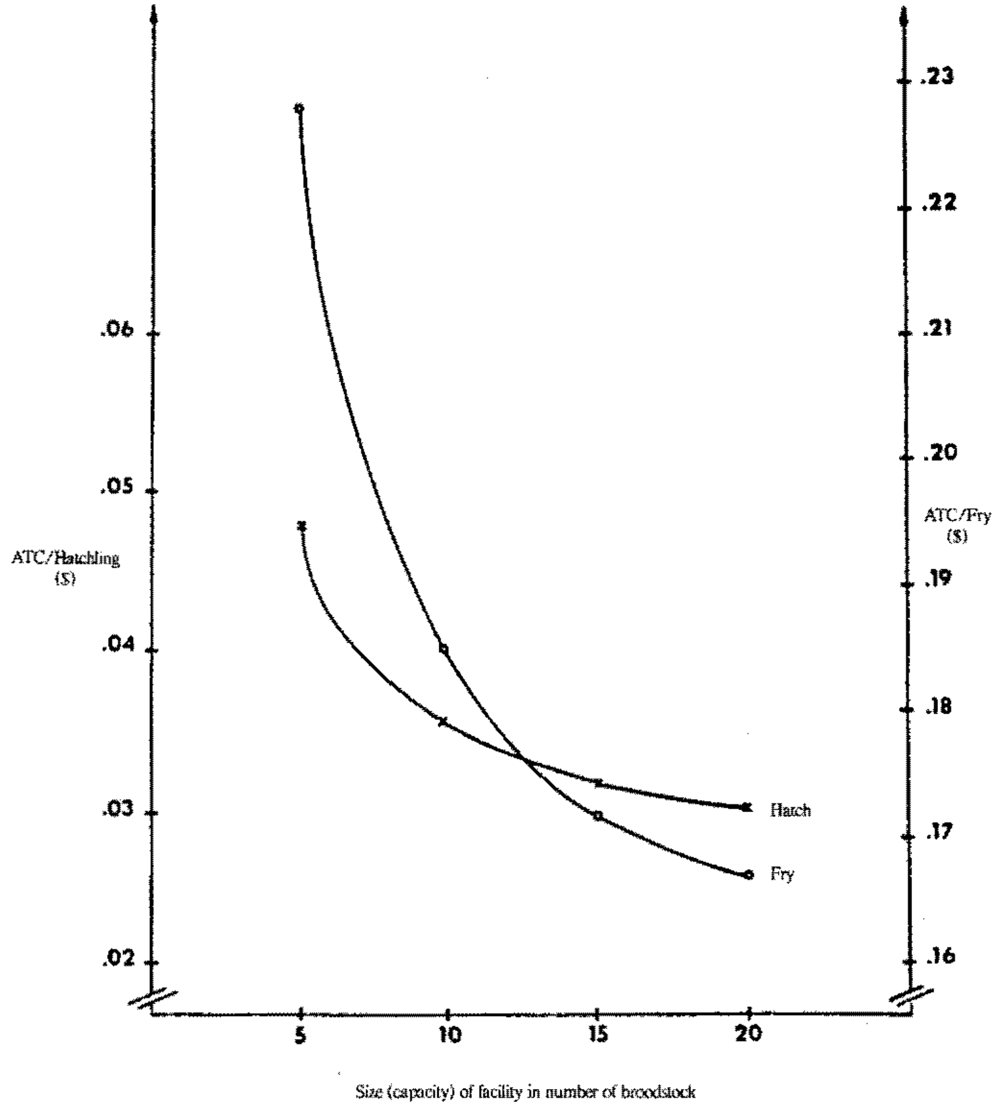

Figure 3. Long-run average cost curves for the production of hatchlings and 1-month fry (50 percent marketing strategy).

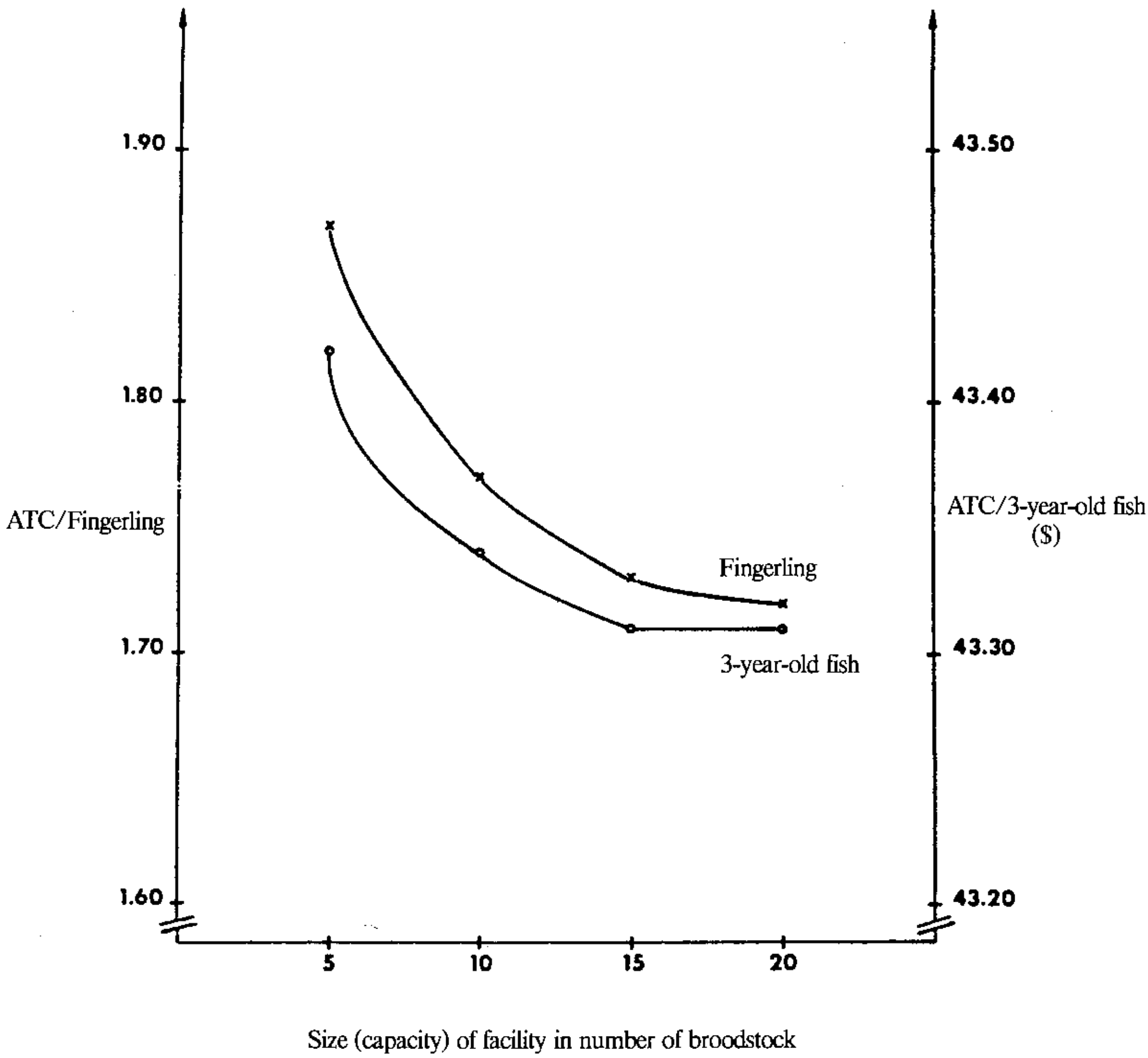

Figure 4. Long-run average cost curves of the production of fingerlings and 3-year-old fish (50 percent marketing strategy).

When annual operating costs for 1- to 3-month growout are compared for the different size facilities (Appendix 9m-o) there are no cost savings. In fact, as facility capacity expands, the per-unit costs of labor, water pumping, and aeration increase slightly. The overall lack of savings in equipment, building, and operating costs seemingly contradicts the data of Table 15 which indicate that ATC per fingerling is reduced with increasing production. However, recall that a portion of the total costs associated with earlier production stages serving as inputs is incorporated in the successive production stages which utilize them. The same is true for any cost savings. Thus the reductions in ATC per fingerling which accompany increased production reflect a portion of the cost savings associated with the production of 1-month-old fry. (Similarly, ATC per fry includes a portion of the cost savings derived by hatchery operations as production increases; and ATC per 3-year-old fish incorporates some of the cost savings associated with fingerling production.)

Cost per 3-Year-Old Fish

As facility capacity is increased, the production of 3-year-old fish requires a more-than-proportionate increase in the number of 12- and 30-foot diameter tanks; however, there are less-than-proportionate increases in aeration system requirements (Appendix 9d-f). As facility capacity expands, additional aeration systems are required only if the increased number of tanks exceeds the unused capacity of the existing aeration system. Table 4 and Appendix 9g-i break down building square footage requirements for the production of 3-year-old fish into separate requirements for growout period from: (1) 3 months to 1 year of age, (2) 1 to 2 years of age, and (3) 2 to 3 years of age. The sum of these separate building requirements increases more than proportionately when production increases. As with the other three production stages, one quarter of the cost savings associated with joint equipment is assigned to the production of 3-year-old fish.

Annual operating costs have also been separately identified for the growout periods from 3 months to 1 year of age, 1 to 2 years of age, and 2 to 3 years of age. Increasing production leads to aeration cost savings, resulting from better utilization of the capacity of the aeration systems.

Alternative Marketing Strategies

In this series of simulations, all facilities begin operations with the same number of broodstock as the base model facility (10). Thus broodstock fishing, spawning and incubation activities under different marketing strategies duplicate those of the base model facility. The production of fry, fingerlings, and 3-year-old fish (and associated costs of production) will differ according to marketing strategy. Appendix 10a-d describes the production resulting from the alternative marketing strategies examined. Appendix 10e lists the average value (over 10 years of operation) for fixed, variable, and total costs of production associated with each production stage. As the marketing strategy increases the proportion of production sold, input requirements are reduced as the numbers of fry, fingerlings, and 3-year-old fish produced decrease. Thus ATC will decrease only if reductions in the amount of fry, fingerlings, or 3-year-old fish produced are accompanied by more-than-proportionate reductions in total cost. The percent reduction in output and associated costs when marketing strategy is increased from 10 percent to 25 percent, 25 percent to 50 percent, 50 percent to 75 percent and from 75 percent to 90 percent are presented in Appendix 10f. For example, 457,213 fry are produced when a facility follows a 10 percent marketing strategy; 381,011 fry are produced under a 25 percent marketing strategy. Thus, as indicated in Appendix 10f, when the percent production sold increases from 10 percent to 25 percent, fry production is reduced by 16.67 percent (1 – (381,011/457,213)). Percent reductions in fixed cost, variable cost, and total cost are similarly calculated from cost information in Appendix 10e. In general, percent reductions in output are accompanied by even greater percent reductions in the total cost of production.

The ATC per unit of production changes (see Table 15) as the marketing strategy of a facility increases the percentage of production sold at the stages of hatch, fry, and fingerling. ATC per hatchling consistently decreases as the percent production sold increases from 10 percent to 90 percent. At the 10 percent marketing strategy, the average ATC per hatchling over 10 years of operation is 3.6 times that of the base model ATC. At the 25 percent marketing strategy, the ATC per hatchling is on average 2.3 times that of the base model. At the 75 percent and 90 percent marketing strategies, ATC per hatchling is less than the base model value by an average of 47.2 percent and 55.6 percent, respectively.

Over the 10 percent to 75 percent marketing strategy range, ATC per fry decreases; but at the 90 percent marketing strategy it reverses this trend and increases (see Table 15). At the 10 percent and 25 percent marketing strategies, ATC per fry is an average (for the 10-year period of operations) of 2.50 and 1.78 times greater than the base model ATC. At the 75 percent marketing strategy ATC per fry is reduced by an average of 27.6 percent (as compared to base model ATC per fry); at the 90 percent marketing strategy it is reduced by an average of 4.9 percent.

As the percent production sold increases up to (and including) 75 percent, ATC per fingerling decreases. At the 10 percent and 25 percent marketing strategies, ATC per fingerling is an average of 30.5 percent and 16.4 percent higher than the base model ATC (see Table 15). There is not a great difference in ATC per fingerling when the base model facility (i.e., the 50 percent marketing strategy) is compared with a facility following a 75 percent market strategy, but at the 90 percent marketing strategy ATC per fingerling reaches its highest level (for all the marketing strategies examined) and is an average of 51.4 percent greater than the base model ATC per fingerling. This discrepancy will be discussed below.

The ATC per 3-year-old fish shows a slight reduction as the marketing strategy increases the proportion sold for a given stage of production from 10 percent to 90 percent; however, the average reductions in ATC are relatively small as indicated in Table 15.

Cost per Hatchling

The production of hatchlings is identical to that of the base model facility regardless of the marketing strategy followed by a facility (Appendix 10a-d). Base model equipment requirements and operating costs for production of hatchlings listed in Tables 2 and 8 are repeated at the various marketing strategies as indicated in Appendices 10e-h and 10k-n. ATC and AVC per hatchling are based on the total number of hatchlings produced (which is constant at 808,582 hatchlings per year) not the number retained. Since annual operating costs remain constant at the various marketing strategies, so does AVC per hatchling. While marketing strategy does not influence the amount of hatchlings produced or equipment requirements specific to hatchery operations (compare equipment requirements for hatchery operations in Table 2 with those in Appendix 10e-h), it does directly determine the proportion of hatchlings, fry, and fingerlings sold versus retained for continued growout, and hence affects equipment and operating costs for the subsequent growout of hatchlings not sold. However, the economies in joint equipment requirements produce a reduction in ATC per hatchling as the marketing strategy increases the proportion of a production sold despite the fact that operating costs and equipment requirements specific to hatchery operations remain constant.

Cost per Fry

As the proportion of production sold is increased from 10 percent to 25 percent, 25 percent to 50 percent and from 50 percent to 75 percent, the percent reduction in total cost of fry production exceeds the percent reduction in fry produced. Thus ATC per fry decreases as shown in Table 15. The percentage reductions in fixed costs are large, due principally to reduced requirements for emergency generator capacity, wells, and nitrogen stripping towers (Appendix 10i-l). Percent reductions in the cost of joint equipment exceed percent reductions in fry production. For example, when marketing strategy changes the percent sold from 10 percent to 25 percent, production of fry is reduced by 16.67 percent and the cost of joint equipment falls by 41.3 percent.

Previously, increases in the percent production sold resulted in greater than proportionate reductions in the cost of joint equipment; however, when changing from a 75 percent to 90 percent marketing strategy, the number of larval tanks required decreases, but freezer and aeration system requirements remain unchanged (Appendix 10e-h and Table 2). Thus, these equipment costs are reduced less than proportionately as compared to reductions in fry production (and the disparity increases as the percent output sold increases). When this occurs ATC will increase.

Cost per Fingerling

As the proportion of production sold increases from 10 percent to 75 percent, percent reductions in the number of fingerlings produced are associated with even greater percent reductions in the total cost of fingerling production. Thus the ATC per fingerling falls as marketing strategy changes from 10 percent to 75 percent (as indicated in Table 15). Reductions in fixed costs, largely the result of reduced joint equipment requirements (described previously), account for the savings in total costs (Appendix 10i-l and Table 3).

When 90 percent of output is sold instead of 75 percent, the resultant percent reduction in the number of fingerlings produced exceeds percent reduction in fixed costs, variable costs, and thus total costs. Hence ATC and AVC per fingerling both increase (Table 15). Although joint equipment requirements are reduced, they are not a source of relative cost savings in this case. In fact, the annual cost of joint equipment allocated to fingerling production is largely responsible for the increase in ATC per fingerling observed when marketing strategy changes from 75 percent to 90 percent. The cost of joint equipment associated with the 75 percent and 90 percent strategies is converted into annual depreciation costs in Appendices 10q and 10r. The annual cost of joint equipment for fingerling production in year i is calculated as: .25 (Annual joint equipment cost in year i)/(Number of fingerlings produced in year i). Depending upon the year of operation, this cost ranges from $.13 to $.45 under the 75 percent marketing strategy, and from $.54 to $1.99 under the 90 percent marketing strategy. Requirements for 12-foot diameter tanks and automatic feeders are reduced proportionately in comparison to fingerling output, but aeration system requirements are not (Appendix 10i and 10j). This occurs because the model specifies aeration systems can only be purchased in discrete units. As a result, the 69.16 percent reduction in the cost of water aeration is also less than the 75 percent reduction in fingerling output.[8]

[8]Calculated from water aeration cost information in Appendices 10o and 11p: 1 - ($177/$574) = 69.16 percent.

Cost per 3-Year-Old Fish

Over the range of alternative marketing strategies examined, each incremental increase in percent output sold, produces reductions in ATC. The percent reductions in total and variable costs just slightly exceed the percent reductions in output of 3-year-old fish and thus result in only small decreases in ATC (see Table 15).

When the proportion of output sold increases, accompanying reductions in equipment requirements produce savings in fixed costs (Appendix 10e-h). Recall fish are cultured in 12-foot diameter tanks from the ages of 1 to 3 months. Three-month-old fingerlings not sold continue growout in 12-foot diameter tanks until the age of six months when they are then transferred to 30-foot diameter tanks. In some cases, additional 12-foot diameter tanks (in excess of those required for growout from one to three months of age) may be necessary to accommodate growout of fingerlings to 6 months of age at the desired stocking density. When the marketing strategy changes from 10 percent to 25 percent and from 25 percent to 50 percent, reductions in the required number of 12-foot diameter tanks (for the continued growout of retained fingerlings) produces cost savings. Furthermore, at the 75 percent and 90 percent marketing strategies, the number of 12-foot diameter tanks required for growout from one to three months of age is sufficient for the continued growout of retained fingerlings. Hence no additional 12-foot diameter tanks need be purchased. The number of 30-foot diameter tanks required changes in proportion to changes in output. One aeration system has capacity for four 30-foot diameter tanks. Thus, situations of excess aeration capacity are more likely to be avoided since a reduction of only four 30-foot diameter tanks eliminates one aeration system.

Economies of Size and Product Mix

In this part of the analysis, both size and product mix were altered. Given the four size categories and the five marketing strategies, 20 combinations were evaluated. The results can be considered as points on a multi-dimensional cost (revenue or rate of return) surface encompassing these dimensions. From such a surface, management can then analyze the outcomes of different planning options and select that option which best meets its objective function (e.g., highest profit, best rate of return, etc.).

The isolated effects of size and marketing strategies considered ATC. Here, however, we shall view total cost, total revenue and rate of return. Because costs vary from year to year, one year (year 5) was selected as representative for cost and revenue evaluation purposes.

The results of the 20 model formats are given in Tables 16 through 21. For analytical exposition, functional relationships for these "surfaces" were estimated and will be reported below. Based on the tables of results, the general premise was that cost, revenue and rate of return were related to management decisions regarding size, marketing strategy. A variety of functional forms and transformations of variables was considered. An interaction (cross product) term for size and marketing strategy was utilized as was a squared term for marketing strategy where appropriate. The functional forms included regular linear relationships, nonlinear relations using a squared term, logarithmic relationships, and transcendental functions. Selection of the functional results presented here relied for the most part of comparisons of the coefficients of determination (R^2 values) and the mean absolute deviation of predicted from actual values.

Reliance on coefficients of determination in engineering economics studies, however, can be erroneous. Relatively high R^2 values are to be expected since the performance measures from the systems model generally follow directly from the model builder's specifications of the internal operations of the system. Therefore, evaluation is needed with respect to the predictive ability of the resulting functions as well as whether the predictions yield "reasonable" results (e.g., nonnegative forecasts).

Joint Output

As a possible single measure of production, a firm's biomass output was defined as simply the kilograms of fish produced, regardless of product mix. Of course, this is an imperfect measure if one considers all combinations of plant size and marketing strategies because different combinations of marketing strategies and size could yield the same biomass for different cost levels. However, for the divergent set of marketing strategies used here, the problem did not occur.

Given the biological functions, biomass would be expected to increase with the size of the plant. On the other hand, as the marketing strategy calls for higher percentages to be sold at each stage, biomass would be expected to decrease. As evident from Table 16, production behaves as expected, reaching a peak for the largest scale of operation with the lowest marketing percentage and dropping rapidly as larger percentages of fish are sold at younger ages.

The general functional relationship considered initially was

Biomass = f(size, strategy, strategy squared, interaction)

where biomass = kilograms of fish produced each year at full production
size = number of broodstock
strategy = percent of fish marketed at initial three selling stages (e.g., 10, 25, etc.)
interaction = (size) × (strategy)

Table 16

Aggregate Production (kilograms) of all Fish by Plant Capacity and Product Mix

Marketing Strategy[a]	Plant Capacity (No. of Broodstock)			
	5	10	15	20
	kilograms			
10	1,027,100	2,054,300	3,081,400	4,108,500
25	594,740	1,189,500	1,784,300	2,379,000
50	176,530	353,060	529,610	706,140
75	22,180	44,378	66,570	88,763
90	1,444	2,895	4,346	5,798

[a]In Tables 16-23, marketing strategy means the percent sold in each size category through the fingerling stage. All remaining fish are sold at three years of age.

Table 17

Total Production Costs by Plant Capacity and Product Mix (year 5)

Marketing Strategy	Plant Capacity (No. of Broodstock)			
	5	10	15	20
	dollars			
10	6,834,772	13,647,095	20,464,917	27,277,584
25	3,999,572	7,976,890	11,954,669	15,931,013
50	1,234,813	2,442,487	3,651,578	4,862,587
75	193,333	358,780	523,617	688,042
90	40,521	57,313	73,347	91,532

Table 18

Total Revenue by Plant Capacity and Product Mix (year 5)

Marketing Strategy	Plant Capacity (No. of Broodstock)			
	5	10	15	20
	dollars			
10	9,090,472	18,181,140	27,271,872	36,362,540
25	5,310,061	10,620,316	15,930,509	21,240,700
50	1,641,176	3,282,353	4,923,660	6,564,901
75	272,065	544,196	816,328	1,088,460
90	79,359	158,783	238,209	317,633

Table 19

Average Total Cost Per Kilogram

Marketing Strategy	Plant Capacity (No. of Broodstock)			
	5	10	15	20
	dollars			
10	6.65	6.64	6.64	6.64
25	6.72	6.70	6.70	6.70
50	6.99	6.92	6.89	6.89
75	8.72	8.08	7.86	7.75
90	28.06	19.80	16.88	15.79

Table 20

Profit by Plant Capacity and Product Mix (Year 5) for Base Model Prices[a]

Marketing Strategy	Plant Capacity (No. of Broodstock) 5	10	15	20
	dollars			
10	2,255,700	4,534,043	6,806,954	9,084,956
25	1,310,489	2,643,426	3,975,838	5,309,685
50	406,363	839,866	1,272,082	1,702,314
75	78,732	185,416	292,711	400,417
90	38,838	101,470	164,862	226,101

[a]Prices are specified as hatchling $.15 each, fry $.45 each, fingerlings $1.25 each, and 3 year-old fish $4 per pound.

Table 21

Investment Requirements for First Three Years of Operation

Plant Size / Marketing Strategy	Year of Operation 1	2	3
	dollars		
Size = 5			
10	10,310,885	4,450,451	11,056,219
25	6,394,722	2,585,445	6,388,998
50	2,336,221	764,093	1,896,393
75	635,891	86,455	244,951
90	284,709	1,500	17,620
Size = 10			
10	20,424,202	8,901,755	22,108,586
25	12,588,098	5,155,623	12,792,616
50	4,466,524	1,521,980	3,791,286
75	1,016,027	187,530	474,635
90	344,079	17,620	15,267
Size = 15			
10	30,544,480	13,350,706	33,163,304
25	18,748,372	7,723,448	19,193,882
50	6,594,134	2,284,573	5,686,179
75	1,383,424	288,605	704,319
90	403,936	31,387	29,034
Size = 20			
10	40,622,384	17,802,010	44,229,440
25	24,927,856	10,307,393	25,583,732
50	8,733,713	3,044,813	7,581,072
75	1,777,964	375,913	947,770
90	468,344	29,034	45,154

Functions were estimated by ordinary least squares regression. While R^2 values above .90 were obtained in many cases, the precise relationship estimated frequently did not predict well over the entire range of data. For example, negative values were forecast for some size-strategy combinations. The equation yielding the best performance both in terms of R^2 and prediction characteristics was transcendental with the following parameters:

$$\ln(\text{biomass}) = 13.22454 + \underset{(.01132)}{.09134}\,\text{Size} + \underset{(.01038)}{.0221}\,\text{Strategy} - \underset{(.00001)}{.001}\,\text{Strategy}^2$$

$R^2 = .9894$

The figures in parentheses are standard errors.

This function behaves as expected. When size remains constant, biomass decreases with increased percentage marketed at the smaller weights.

Thus, even though various combinations of percentages and size could produce the same biomass, a strong relation is evident among these variables, a relationship which is useful in studying costs and revenues.

Costs and Revenues

The simulation results for total costs and revenues are summarized in Tables 17 and 18. Both follow similar patterns, increasing with respect to size and decreasing with higher percentages of fish marketed at small sizes.

The economies of size reported for individual sizes of fish under the base model marketing strategy also persist over different strategies when considered on a per-kilogram basis, as shown in Table 19. Given the nature of some of the equipment and joint cost items which may not vary much with marketing strategy, the per-unit costs go up as more fish are sold at smaller weights. The scale economies are much more pronounced, however, at the higher sales strategies.

Cost could be viewed as a function of the same variables used in the biomass relation, or, it could be analyzed as a function of biomass instead. Relations of both types were evaluated using the several functional forms described earlier. Again high R^2 values were obtained; however, a linear form relating cost to biomass gave the best results in terms of both R^2 and predictive performance.

$$\text{Total cost} = 75555.73917 + \underset{(.00917)}{6.62951}\,\text{Biomass}$$

$R^2 = 1.000$

where total cost = total annual cost excluding income tax for year 5.

Fitting a function relating total revenue to biomass is not appropriate in this case because the nature (form) of the functional relationship depends in a large measure on the price relations among the four sizes of sturgeon being sold. This aspect of the analysis will be discussed later under the sensitivity of the model's results to prices.

Profits for the currently specified set of prices, however, are shown in Table 20 for the various plant sizes and marketing strategies.

The implications of these functional relations for managerial decisions will be discussed following the results for the rate of return.

Rate of Return

The rate of return is one measure of the relative worth of an investment alternative. In this analysis, the rate of return was computed for the 10-year planning horizon. A different time span would, of course, yield different results.

The annual cash flow used in calculating the rate of return was the net profit (loss) after income taxes with the depreciation charges then added back in.

The cash outflow is the annual investment requirement for land, buildings, and equipment. The initial investment in land, buildings and equipment is spread over the first three years of operations as the plant reaches maturity. After that point, a fixed charge for replacement of nets of $1,500 per year is assessed for all plants.

Table 21 shows the investment requirements for the initial 3-year period for the various plants considered. Investment is assumed to be made at beginning of the year cited.

The rate of return (see Table 22) shows a definite increase with the higher percentages of fish sold at small sizes and with larger scales of plants. In fact, the peak rate of return is associated with the limiting scale (20 broodstock) and marketing strategy (90 percent) used in this study. As seen in Table 21, the investment requirements for handling the smaller fish reflect a major reduction over the needs for similar plants which carry most of their output to adult size.

In relating the management decisions to the rate of return, a transcendental function showed the best predictive power with the following estimates:

$$\ln(\text{rate}) = .70553 - \underset{(.00661)}{.06117}\,\text{Strategy} + \underset{(.00001)}{.0008}\,\text{Interaction} + \underset{(.00001)}{.00084}\,\text{Strategy}^2$$

$R^2 = .9812$

This equation illustrates that as size of plant is held fixed, the rate of return increases (after a small initial decline) as larger percentages of fish are sold at the initial stages of growout. Similarly, as the product mix remains unchanged, the rate of return increases slightly with size of facility through the interaction term.

Table 22

Rate of Return on Investment by
Capacity and Product Mix

Marketing Strategy	Plant Capacity (No. of Broodstock)			
	5	10	15	20
	percent			
10	1.15	1.21	1.22	1.24
25	1.01	1.12	1.16	1.18
50	0.92	1.26	1.39	1.43
75	2.22	4.72	5.77	6.21
90	9.01	19.76	25.72	30.10

Implications

Evaluation of the above functions provides valuable information for long-run planning by management. The results demonstrate clearly that management at the outset of planning must define its objective function (or company goal) because the decisions from the above set of functions differ with the goals of management.

The linear cost and revenue functions indicate that the most *profit* is obtained with plant size at its largest level and marketing strategy at its lowest percentage—or, where biomass is the largest. This relation indicates that raising fish to larger weights is preferable in terms of profit before taxes.

However, operations with the greatest profits do not provide the highest *rate of return* on the investment. In this case, the rate of return increases as the size of plant goes up and *as percentage sold rises*. The latter condition is associated with a small biomass while the highest profit is related to a large biomass.

The above functions also permit management to consider trade-offs between profits and rate of returns. Thus, a firm with a lexicographic ordering of goals could seek the highest profit *after a satisfactory rate of return had been achieved* or vice versa. In this case, management could determine which combinations of size and product mix afforded satisfactory achievement of the restricting goal and then optimize their decision with respect to the second objective.

Sensitivity to Price Changes

The above discussion is conditioned on the specified set of *prices* received for the four sizes of sturgeon. If the relative or absolute levels of these prices change, the appropriate management decisions regarding marketing strategy and scale of plant may also change.

Several sets of prices were postulated to test the sensitivity of plant size and marketing strategy to these factors. Given the outcome of the base model with its initial set of prices, any reduction in the prices of hatchlings and/or fry would still leave the optimum strategy unchanged, although profits and rate of return would be reduced. The plants with the largest biomass (20 broodstock and a 10 percent marketing strategy) maintained the largest profit level.

However, when the price of 3-year-old fish is reduced to $3 per pound from the original $4 per pound and all other prices remain unchanged, the most profitable marketing strategy becomes that of selling fish at smaller sizes (i.e., the 90 percent marketing strategy). The profit levels of the various combinations of sizes of plants and marketing strategies are given in Table 23. The table illustrates that scale of operation is still an important influence on profit but that, for each scale, marketing fish at smaller sizes provides the greatest profit—a decision strategy opposite from that reflected by the base price results in Table 20.

Thus, in its long run planning for capacity and marketing, management should carefully evaluate the projected prices at which the products can be sold.

Table 23

Profit by Plant Capacity and Product Mix (Year 5) for Alternative Prices[a]

Marketing Strategy	Plant Capacity (No. of Broodstock) 5	10	15	20
10	-8,019	6,556	15,682	29,916
25	473	23,347	45,710	69,509
50	18,217	63,574	107,611	149,681
75	30,228	88,392	147,167	206,352
90	35,749	95,276	155,563	213,697

[a]Prices are specified as hatchling \$.15 each, fry \$.45 each, fingerling \$1.25 each and 3-year-old fish \$3 per pound.

CONCLUSIONS

The results from the simulations demonstrate that sturgeon production costs and rates of return are sensitive to both size of facility and product mix. Economies of size were exhibited over the range of capacities examined, while the rate of return was more sensitive to changes in marketing strategies. In addition, management marketing strategies based on profits were sensitive to prices of larger fish.

Given the price schedule and underlying functions utilized by the present systems model, the production of fingerlings (growout from one to three months of age) and fish (growout from three months to three years of age) should be evaluated carefully. This conclusion is supported by the relative increases in ATC for fingerlings as larger proportions of remaining fish are sold at each stage. And, as reflected by analysis of the multi-dimensional rate of return surface, marketing strategies which sell the majority of production at the stages of hatch and fry give greater return than those which retain a majority of production for growout to three years of age, assuming the price relations used in the initial model.

This study examined simulation experiments relating to size and marketing strategies; however, numerous other situations involving changes in biological, economic, and/or operating conditions may be simulated. One can hypothesize about the outcome of interactive effects by specifying change in more than one biological, economic, and/or operating condition of the systems model during a simulation experiment. For example, raising the stocking density level may simultaneously result in an increase in mortality and a decrease in growth rate. The net effect on the production and profitability of a facility is determined by the nature of these changes and their interactions with one another.

In this sense, the systems model in this study is a first-round version, based largely on experimental data. Due to the lack of information regarding the biological response of sturgeon to alternative intensive culture environments, operating conditions specified in the model are not necessarily the most economically efficient means of providing a suitable culture environment. Aquaculture-oriented experiments are needed to better characterize oxygen and feed consumption, resultant metabolite production and ensuing growth and survival rates of sturgeon under intensive culture conditions. The impact of temperature changes on factors such as disease and mortality rates also needs study. A better understanding of oxygen consumption and metabolite production leading to improved delineation of stocking density levels and water flow rates also should be research priorities. Any possible reductions in equipment (tanks, aeration systems) and joint equipment (wells, nitrogen stripping towers, emergency generator capacity) requirements which may result would be important moderators of production costs. This is particularly important in the production of fingerlings and 3-year-old fish since the cost of utilities (for pumping and aerating water) and joint equipment are major components of ATC per unit for these two stages of production.

In the present systems model, input requirements are determined once the size and marketing strategy of the facility have been specified. Future economic research could examine situations where there is a discrepancy between the *planned* and *actual* number of broodstock obtained and/or marketing strategy implemented. What is the economic outcome if less broodstock are obtained than anticipated? What are the short-run costs (if any) of unused capacity should a facility increase its marketing strategy, selling a greater percentage of a given production stage(s) than originally planned?

Another item of prime economic importance in future sturgeon research is the capability of producing sturgeon roe (used as the base for caviar) by growing female fish to larger sizes. Data in this study apply to fish 3 years of age or younger; to date (1986) female sturgeon raised at the U.C. Davis Aquaculture Facility have not reached sexual maturity. Given the luxury demand for caviar, the economic implications of adding roe as a joint product with adult female fish are sizable and should be studied in future research.

The value of simulation data at this early developmental stage of the systems model of sturgeon aquaculture lies in the nature of change predicted by the model rather than the precise quantitative aspects of change. The model is flexible and can readily incorporate new, additional information. Hence it serves as a starting point for revision, improvement, and elaboration. As the model building process continues, resultant simulation experiments will more accurately assess the economic feasilibity of the production process.

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APPENDICES

Appendix A: Operating Procedures

Artificial propagation and culture of white sturgeon begins with broodstock collection during April and May when the animals migrate up river to their spawning grounds. Following capture, fish are transported back to the facility in a portable tank supplied with aerated water. Surgical techniques (Doroshov *et al.,* (1983)) are used to determine the sex of the animal and stage of gonadal maturation. While in captivity, broodstock do not feed and are individually maintained in separate halves of a 1,795-gallon rectangular tank supplied with flowing water.[9]

Ovulation is hormonally induced in female broodstock with carp *(Cyprinus carpio)* pituitary extracts. If not already naturally occurring, a spermiation in male broodstock can also be hormonally induced. Two intramuscular injections are given at 12 and 24 hour intervals. Females receive a total dosage of 5 mg per kg of body weight; males, a total dosage of 1 mg per kg of body weight. Ova are collected from the female through a midventral incision. Sperm are collected by manual stripping and catheterization.

In vitro fertilization and incubation techniques for white sturgeon have been previously described by Doroshov *et al.,* (1983). Eggs are placed in bowls, then mixed with diluted sperm (1 part seminal plasma: 200 parts water). Following repeated washing with water, fertilized eggs are mixed with a suspension of silt. Silt particles adhere to the external jelly coat of eggs, thus preventing them from sticking to one another and forming clumps which would promote fungal growth and result in suffocation of the eggs.

The incubation system is comprised of 10 domed-bottom plexiglass jars (3.4-gallon), each with a capacity of holding approximately 70,000 eggs. The annual capacity of the incubation will exceed 700,000 eggs because more than one incubation run can be conducted during a spawning season. Each incubation jar receives sterilized flow-through water from an elevated head tank (Monaco and Doroshov, 1983). The flow of water through the incubation jar (see Appendix 1) rotates the eggs, promoting oxygenation and inhibiting fungal growth. Eggs hatch over a 20- to 35-hour period after seven days of incubation at an average water temperature of 14.5°C. Larvae swim vertically, exit the incubation jar through a spout, and are carried by a drain gutter to a holding trough.

From the holding trough of the incubation system, larvae are transferred to a 489-gallon, square tanks with rounded corners at a density of 25,000 per tank where they remain for the first month posthatch. Newly hatched larvae obtain nutrition from a yolk sac and do not commence external feeding until approximately day 10 posthatch. Larvae are offered a semi-moist artificial feed *ad libitum* eight times daily for the first week of feeding. During the second week of feeding, larvae are gradually weaned form the semi-moist to a dry artificial feed. Not all larvae will accept an artificial feed; and of those that do, not all will be successfully weaned. Hence mortality is highest during this period. Larval tanks are cleaned twice daily to remove excess feed.

From the age of one to six months, animals are maintained indoors in 12-foot diameter tanks; thereafter, they are reared outdoors in 30-foot diameter tanks shaded by roofing (see Appendix 1 for water depth and flow rates). Feed is dispensed from automatic feeders for the 12-foot and 30-foot tanks. Animals are initially stocked at one-half the amount specified by a stocking density function. When growth and mortality result in a total biomass equal to that specified by a stocking density function, animals are transferred to a larger number of tanks, again at one-half the level dictated by the same stocking density function. The process is repeated until the animals are marketed.

Establishing the stocking density is an operating procedure which greatly influences the culture environment. In trout it was shown to be inversely related to growth rate and directly related to the feed conversion rate (Refstie, 1977). Increases in stocking density produce stress in channel catfish as measured by certain hematological parameters (Klinger, Delventhal, and Hilge, 1983).

The stocking density function reflects, in part, the metabolic processes of the fish. Typically, the metabolic rate per unit weight (measured in terms of oxygen consumption) decreases as size increases (Fry, 1971).

[9] See Appendix 1 for a list of the types of tanks or other containers used in each phase of production and the temperature, depth, volume, and flow rate of water associated with each.

Smaller size fish have a greater metabolic rate than larger size fish and hence require a greater water volume per unit weight in order to obtain enough oxygen. In this context, the stocking density function expressed in grams of biomass (total body weight) per cubic foot of water (based on preliminary data from UC Davis) increases at a decreasing rate with the weight of the individual fish. The data used in estimating the relationship were observed densities used at the UC Davis aquaculture facility for sturgeon production. Data were not available on interactions of stocking density and mortality or feed consumption.

(1) Grams biomass per ft^3 water $= \underset{(.060)}{48.9843}(\text{Weight})^{\underset{(.009)}{.3072}}$

($R^2 = .9971$)

The weight variable is expressed in grams per fish. Figures in parentheses are the standard deviations for the coefficients.

The stocking density function is not applicable to incubation operations nor to production stage II. Larval tanks are stocked at a constant 25,000 hatchlings per tank.

Production is based on flow-through water derived from wells on site; no water is recirculated through any part of the facility. Sturgeon grow well in a relatively wide range of water temperatures; hence water is not heated and ranges in temperature from 13 to 20°C. Flow rates vary with the stage of growout.

The level of nitrogen in the water can adversely affect the health of fish. Water is considered saturated with nitrogen gas when it contains all the dissolved gas it can hold at a given temperature and pressure (Gordon and Ford, 1972); however, under conditions of increased pressure (as may occur during pumping) groundwater may absorb even greater quantities of dissolved gas, becoming "supersaturated" with nitrogen. Fish cultured in water containing high levels of nitrogen gas may incur stress, increased susceptibility to secondary infections and gas bubble disease (Rucker, 1972; Bouck, 1980); therefore, all well water is first passed through a packed column aeration system (or "nitrogen stripping tower") prior to entering the hatchery and growout facility to reduce the dissolved nitrogen levels (Speece, 1981; Hackney and Colt, 1982; Marking, Dawson, and Crowther, 1983). A regenerative air blower system (described in Appendix 2) provides additional aeration of water.

The water used (as calculated in Appendix 3) is discharged *without pretreatment* onto neighboring agricultural lands. Effluent water may require treatment to meet state or Environmental Protection Agency water quality standards; however, this study does not consider alternative methods of effluent treatment, nor the costs of doing so.

Appendix B: Biological Functions

The model's biological functions quantify the physical response of animals to the culture environment specified above. The biological functions in this study were based on data from the UC Davis aquaculture facility.

Feed Requirements

The function estimating daily feed requirements per fish was provided by Doroshov (unpublished data from UC Davis aquaculture experiments).

(2) Daily feed per fish (grams) $= 0.056(\text{Age})^{1.845}$

($R^2 = .999$)

where age is expressed in months.

This feeding rate is based on *ad libitum* feeding (i.e., animals are fed to satiety). Food ration and consumption levels are major determinants of body weight; however, given the assumption of *ad libitum* feeding, body weight may be expressed as a function of age. Hence the daily food ration is estimated so as to provide surplus food, and thus permit *maximum* weight gain rather than a particular rate of weight gain.

Body Weight

Two functions (estimated by ordinary least squares regression techniques) relate body weight of individual fish to age. The first applies to fish less than or equal to three months of age, the second to fish from three months to three years of age. (Data for estimation were supplied by UC Davis aquaculture facility.)

(3) Age $\leq$ 3 mos.: Ln weight (grams) $= \underset{(.399)}{-3.9674} + \underset{(.408)}{2.3054}\,\text{Age}$

($R^2 = .9758$)

(4) 3 mos. $<$ Age $\leq$ 3 yrs.: Ln weight (grams) $=$

$\ln \underset{(.239)}{1.42} + \underset{(.096)}{2.3888}(\ln \text{Age})$ ($R^2 = .9613$)

where age is expressed in months.

Body weight can be represented as a single exponential equation with relatively good statistical properties; however, equation 4 yields better predictive results for larger size fish. The body weights resulting from equations 3 and 4 closely coincide at the age of three months at which time the functions predict body weights of 19.08 and 19.59 grams respectively. The results from these equations describe exponential growth for the first three years of culture and are in general agreement with other data

Appendix Table 1

Tank and Water Requirements for Each Production Stage

Activity	Tank Dimensions	Water Depth (feet)	Water Volume (gallons/tank)	Water Flow Rate (gallons/min)	Daily Water Flow Per Tank (gallons/day)	Ambient Water Temperature (°C)
Production Stage I						
Broodstock maintenance	4' x 20'	3.0	1,795	13.2	19,008	12-15
Incubation (days 1-2)			3.4/incubation jar	1.0	1,400/incubation jar	14-16
Incubation (days 3-7)			3.4/incubation jar	2.0	2,880/incubation jar	14-16
Production Stage II	6.6' x 6.6'	1.5	489	5.0	7,200	16-18
Production Stage III	12' diameter	1.5	1,269	10.0	14,400	12-20
Production Stage IV						
3-6 months	12' diameter	1.5	1,269	10.0	14,400	12-20
6-12 months	30' diameter	2.5	13,218	40.0	57,600	12-20
12-24 months	30' diameter	3.5	18,507	51.4	76,016	12-20
24-36 months	30' diameter	3.5	18,507	51.4	76,016	12-20

Source: U.C. Davis Aquaculture Program and industry estimates.

collected from growth experiments where white sturgeon were grown under similar conditions and fed natural (tubifex and *Artemia salina*), artificial or a combination of natural and artificial diets (Monaco, Buddington, and Doroshov, 1981). The present study does not address the issue of size distribution of fish at a given age; rather, expected values are utilized (i.e., all individuals of the same age are considered to be the same size). The data pertain to three annual cohorts of sturgeon; extrapolation of the biological functions beyond this age is inappropriate.

Mortality

Based on experimental data from the UC Davis aquaculture program, most mortality was observed to occur within the first month posthatch (days 10-30), the period when larvae most successfully initiate and maintain external feeding on an artificial diet. After the age of 3.5 months (or a weight of approximately 30 grams) fish were relatively hardy and further mortality (through three years of growout) was negligible *under the specified culture conditions.* Mortality was fit by ordinary least squares regression as a logistic function of age in months with the following results:

$$\text{(5)}\quad \text{Cumulative proportion dead } i = \frac{.53}{1 + e^{(3.1763 \quad 4.0301\,Age)}}$$

$$(.299)(.277)$$

$$R^2 = .9171$$

The cumulative proportion dead in month i becomes asymptotic to .53; thus, about 47 percent of the original hatch survive to 3 years of age.

Appendix Table 2

Aeration System Specifications[a]

Blower Size (horse power)	Maximum Capacity Per Blower	Water Depth (feet)	Cubic Feet Air Per Tank	Pressure (psi)	Cost[b] (dollars)	KW Consumption
2	12, 4' x 20' tanks	3.0	9.0	2.5	2,075.88	2.7
3	17, 6.6' x 6.6' tanks	1.5	6.0	1.6	1,707.43	1.9
3	8, 12' diam. tanks	1.5	14.0	2.3	2,166.36	2.6
5	4, 30' diam. tanks	2.5-3.5	12.1	2.9	2,476.64	4.5

[a]This information is based on industry sources. An aeration system is comprised of a regenerative blower (plus accessories) and ultra-high molecular weight porous plastic tubing (1-3/8" x 1/8" wall with average pore size of 20 microns or 2-1/10" x 3/16" wall with average pore size of 35 microns) through which air diffuses.

[b]Includes the cost of blower accessories and diffuser tubing.

Appendix Table 3

Annual Water Requirements for the Base Model Facility[a]

Activity	Annual Water Requirements (acre-feet)
Production Stage I	
Broodstock maintenance	7.65
Incubation	1.73
Production Stage II	10.72
Production Stage III	139.18
Production Stage IV	
3-12 months	1,563.28
12-24 months	4,957.87
24-36 months	11,435.12

[a]Annual water requirements were calculated based on water flow rates, number and size of tanks and length of time tanks are occupied.

Appendix Table 4

Building and Outdoor Roofing Requirements

Item	Building Space Per Item[a]	Outdoor Roofing[a] Per Item
	----------square feet----------	
Broodstock tank (4' x 20')	188	
Incubation system	250	
Larval tank (6.6' x 6.6')	100	
12' diameter tank	250	
30' diameter tank		1,600

[a]Total building and roofing requirements were calculated based on this information. For example, the 1,002 square feet building requirement for hatch production in the base model facility (in Table 4) was calculated as: (4 broodstock tanks x 188 square feet/broodstock tank) + (1 incubation system x 250 square feet/incubation system).

Appendix Table 5

Labor Requirements

Activity	Number Hours Per Activity	Number of Persons Required	Total Number Labor Hours
Broodstock fishing[a]	12	3	36
Spawning	3	3	9
Feeding larvae[b]	2	1	2
Cleaning larval tanks[b]	1	1	1
Transfer of fry from larval to 12' diameter tank(s)[c]	1.5	2	3
Transfer of fingerlings from 12' to 12' diameter tank(s)[c]	1.5	2	3
Transfer of fish from 12' to 30' diameter tank(s)[c]	1.5	2	3
Transfer of fish from 30' to 30' diameter tank(s)[c]	1.5	2	3

[a]Requirement per fishing trip including roundtrip travel time (4 hours) to fishing site.
[b]Total hours required per tank per day.
[c]Total hours required per tank to tank transfer.

Source: U.C. Davis Aquaculture Program and industry estimates.

Appendix 6a: Determination of Well Requirements and Costs

The cost of a well is comprised of: 1) the cost of digging a test and production hole, and 2) the cost of the pump. The model assumes for any size well, a flat fee of \$5,625 is charged for mobilization (moving of equipment to the well site) and the drilling and electric logging of the test hole.

Production capacity and the cost of drilling and the casing for the well vary with the size (diameter) of the well. They are estimated as follows:

Well Diameter (inches)	Production Capacity (gallon/min)	Cost (\$/ft)
8	500	40
10	1,000	60
16	2,000	80

The model further specifies: 1) all wells are 400 feet deep, 2) a pump has an efficiency of 80 percent and can deliver 20 gallons of water per minute per hsp, and 3) pump cost is estimated at \$300 per hsp.

Thus the number and total cost of wells required is estimated as follows:

(1) If the maximum water required (MWR) $\leq$ 500 gallon/min:
   (a) the number of wells required = 1
   (b) well cost = \$5,625 + (\$40/ft × 400 ft)
$$+\left(\frac{\text{MWR}}{\frac{20 \text{ gallon/min}}{\text{hsp}}} \times \$300/\text{hsp}\right)$$

(2) If 500 gallon/min < MWR $\leq$ 1,000 gallon/min:
   (a) the number of wells required = 1
   (b) well cost = \$5,625 + (\$60/ft × 400 ft)
$$+\left(\frac{\text{MWR}}{\frac{20 \text{ gallon/min}}{\text{hsp}}} \times \$300/\text{hsp}\right)$$

(3) If 1,000 gallon/min < MWR:
   (a) the number of wells required = MWR/2,000 gallon/min (rounded up to the next integer
   (b) well cost = (Number of wells required) × (\$5,625
$$+ (\$80/\text{ft} \times 400) + \left(\frac{\text{MWR}}{\frac{20 \text{ gallon/min}}{\text{hsp}}}\right.$$
$$\left.\times \$300/\text{hsp}\right))$$

Appendix 6b: KWH and KW Pumping Requirements

The model assumes:

1) Head (total feet well water is lifted) = 150 feet
2) Efficiency of pump (E_p) = 0.80
3) Efficiency of motor (E_m) = 0.80
4) Overall efficiency of pumping ($E_p \times E_m = E_o$) = 0.64
5) KWH required to pump 1 acre foot of water $= 1.024 \times \frac{\text{Head}^a}{E_o}$

Hence 1.024 × 150/0.64 or 240 KWH are required to pump 1 acre foot (325,900 gallons) of water given the above assumptions. The annual KWH cost of pumping for a production stage can now be computed. For example, the annual water requirement for production stage II (base model facility) is 10.72 acre feet. Thus the associated KWH pumping cost is:

$$\$164.66 = 10.72 \text{ acre feet} \times 240 \text{ KWH/acre foot} \times \$0.64/\text{KWH}$$

The model determines KW demand as follows:

$$10.92 \text{ KW} = 10.72 \text{ acre feet} \times 240 \text{ KWH/acre foot} \times 4 \text{ KW}/1{,}000 \text{ KWH}^b$$

[a] From University of California Agricultural Extension Bulletin, July 1978, Irrigation Pumping Costs.
[b] The relationship of 4 KW per 1,000 KWH was based on Pacific Gas and Electric Company estimates.

Appendix Table 7a

Equipment Insurance Cost Schedule

Equipment Value (EV)	Annual Cost of Insurance
----------dollars----------	
EV $\leq$ 50,000	350
50,000 < EV $\leq$ 100,000	650
100,000 < EV $\leq$ 300,000	1,050
EV > 300,000	1,050 + $2 per $1,000 of equipment value in excess of $300,000

Appendix Table 7b

Building Insurance Cost Schedule

Building Value (BV)	Annual Cost of Insurance
----------dollars----------	
BV $\leq$ 45,000	415
BV > 45,000	415 + $9 per $1,000 of building value in excess of $45,000

Source: Industry estimates.

Appendix Table 8a

Unit Cost and Accelerated Cost Recovery Schedule (ACRS) Classification of Fixed Input Requirements

Input Item	Unit Cost (dollars)	ACRS Class (years)
Boat	16,000	5
Fishing nets	500	3
Fish hauler	1,100	5
Broodstock tank	1,595	5
Broodstock tank aeration system	1,972	5
Incubation system	3,600	5
Larval tank (6.6' x 6.6')	450	5
Larval tank aeration system	1,622	5
Freezer	600	5
12' diameter tank	975	5
12' diameter tank aeration system	2,059	5
Automatic feeder	345	5
30' diameter tank	5,000	5
30' diameter tank aeration system	2,353	5
Well	See Appendix 6a	15
Nitrogen stripping tower	4,000	5
Emergency generator	See Appendix 8c	5
Truck	11,250	3

Source: Internal Revenue Service Publications 225 and 534.

Appendix Table 8b

Accelerated Cost Recovery Schedule

Year	ACRS Year Classification 3	5	15
	Annual Percent Recoverable		
1	0.25	0.15	0.10
2	0.38	0.22	0.11
3	0.37	0.21	0.09
4		0.21	0.08
5		0.21	0.07
6			0.06
7			0.06
8			0.06
9			0.06
10			0.05
11			0.05
12			0.05
13			0.05
14			0.05
15			0.05

Source: Internal Revenue Service Publications 225 and 534.

Appendix Table 8c

Emergency Generator Cost Schedule

Emergency Generator Capacity (KW)	Cost/KW (dollars)
KW capacity $\leq$ 15	438
15 < KW capacity $\leq$ 60	300
60 < KW capaity $\leq$ 125	230
125 < KW capacity $\leq$ 500	158
500 < KW capacity $\leq$ 1,000	120

Source: Industry estimates.

Appendix Table 9a

Production From a Five Broodstock Capacity Facility[a] (Per Cohort of Fish)

Marketing Strategy: 50 percent

Age	Body Weight (grams/fish)	Number Produced	Number Sold	Production[b] (kg)
Hatchling	0.016[c]	404,291	202,146	3.23
1 month	0.19	127,003	63,502	12.06
3 months	19.08	47,510	23,755	453.24
6 months	102.60	23,571	0	2,436.85
12 months	537.32	23,571	0	12,761.85
18 months	1,415.41	23,571	0	33,617.40
24 months	2,814.08	23,571	0	66,837.21
30 months	4,795.52	23,571	0	113,898.39
36 months	7,412.82	23,571	23,751	176,061.89

[a]For all stages after hatch, the number produced takes into account mortality and any previous production sold.
[b]Production retained for continued culture or sold at the end of 36 months growout.
[c]Based on mean weight of 12 larvae at hatch (Beer, 1981).

Appendix Table 9b

Production From a 15 Broodstock Capacity Facility[a] (Per Cohort of Fish)

Marketing Strategy: 50 percent

Age	Body Weight (grams/fish)	Number Produced	Number Sold	Production[b] (kg)
Hatchling	0.016[c]	1,212,873	606,437	9.70
1 month	0.19	381,011	190,506	36.19
3 months	19.08	142,533	71,267	1,359.74
6 months	102.60	71,255	0	7,310.76
12 months	537.32	71,255	0	38,286.74
18 months	1,415.41	71,255	0	100,855.04
24 months	2,814.08	71,255	0	200,517.27
30 months	4,795.52	71,255	0	341,704.78
36 months	7,412.82	71,255	71,255	528,200.49

[a]For all stages after hatch, the number produced takes into account mortality and any previous production sold.
[b]Production retained for continued culture or sold at the end of 36 months growout.
[c]Based on mean weight of 12 larvae at hatch (Beer, 1981).

Appendix Table 9c

Production From a 20 Broodstock Capacity Facility[a] (Per Cohort of Fish)

Marketing Strategy: 50 percent

Age	Body Weight (grams/fish)	Number Produced	Number Sold	Production[b] (kg)
Hatchling	0.016[c]	1,617,165	808,583	12.94
1 month	0.19	508,015	254,008	48.26
3 months	19.08	190,044	95,022	1,813.02
6 months	102.60	95,007	0	9,749.72
12 months	537.32	95,007	0	51,049.16
18 months	1,415.41	95,007	0	134,473.86
24 months	2,814.08	95,007	0	267,357.30
30 months	4,795.52	95,007	0	455,607.97
36 months	7,412.82	95,007	95,007	704,269.79

[a]For all stages after hatch, the number produced takes into account mortality and any previous production sold.
[b]Production retained for continued culture or sold at the end of 36 months growout.
[c]Based on mean weight of 12 larvae at hatch (Beer, 1981).

Appendix Table 9d

Equipment Requirements

Total Number of Broodstock: 5
Marketing Strategy: 50 percent

Equipment	Number Required for Years 1-10	Total Cost
		(dollars)
Production Stage I		
Boat	1	16,000
Fishing nets	30	15,000
Fish hauler	1	1,100
Brood tanks	2	3,190
Incubation system	1	3,600
Aeration system	1	1,972
Total		40,862
Production Stage II		
Larval tanks	5	2,250
Freezer	1	600
Aeration system	1	1,622
Total		4,472
Production Stage III		
12-foot diameter tanks	67	65,325
Automatic feeders	134	46,230
Aeration system	9	18,531
Total		130,086
Production Stage IV		
12-foot diameter tanks	67	65,325
30-foot diameter tanks	225	1,125,000
Automatic feeders	584	201,480
Aeration system (12-foot tanks)	8	16,472
Aeration system (30-foot tanks)	57	134,121
Total		1,542,398

Appendix Table 9e

Equipment Requirements

Total Number of Broodstock: 15
Marketing Strategy: 50 percent

Equipment	Number Required for Years 1-10	Total Cost (dollars)
Production Stage I		
Boat	1	16,000
Fishing nets	30	15,000
Fish hauler	1	1,100
Brood tanks	6	9,570
Incubation system	1	3,600
Aeration system	1	1,972
Total		47,242
Production Stage II		
Larval tanks	13	5,850
Freezer	1	600
Aeration system	1	1,622
Total		8,072
Production Stage III		
12-foot diameter tanks	202	196,950
Automatic feeders	404	139,380
Aeration system	26	53,534
Total		389,864
Production Stage IV		
12-foot diameter tanks	202	196,950
30-foot diameter tanks	677	3,385,000
Automatic feeders	1,758	606,510
Aeration system (12-foot tanks)	25	51,475
Aeration system (30-foot tanks)	170	400,010
Total		4,639,945

Appendix Table 9f

Equipment Requirements

Total Number of Broodstock: 20
Marketing Strategy: 50 percent

Equipment	Number Required for Years 1-10	Total Cost
		(dollars)
Production Stage I		
Boat	1	16,000
Fishing nets	30	15,000
Fish hauler	1	1,100
Brood tanks	8	12,760
Incubation system	1	3,600
Aeration system	1	1,972
Total		50,432
Production Stage II		
Larval tanks	17	7,650
Freezer	1	600
Aeration system	1	1,622
Total		9,872
Production Stage III		
12-foot diameter tanks	270	263,250
Automatic feeders	540	186,300
Aeration system	34	70,006
Total		519,556
Production Stage IV		
12-foot diameter tanks	269	262,275
30-foot diameter tanks	903	4,515,000
Automatic feeders	2,344	808,680
Aeration system (12-foot tanks)	34	70,006
Aeration system (30-foot tanks)	226	531,778
Total		6,187,739

Appendix Table 9g

Land and Building Requirements

Total Number of Broodstock: 5
Marketing Strategy: 50 percent

	Land			Building and Roofing		
Production Period	Acres Required	Total Cost	Annual Tax	Square Feet Required	Total Cost	Annual Tax
		--------dollars--------			--------dollars--------	
Hatch production	0.01	43.12	1	626	15,650	157
Hatch to 1 month growout	0.01	34.44	1	500	12,500	125
1 to 3 month growout	0.38	1,153.74	12	16,750	418,750	4,188
3 month to 1 year growout	2.59	7,766.22	78	80,750	741,830	7,418
1 to 2 year growout	2.92	8,761.54	88	84,800	428,081	4,281
2 to 3 year growout	7.27	21,821.18	218	211,200	1,066,164	10,662
Office and lab building	0.07	206.64	2	2,400	139,872	1,399
Total	13.25	39,786.88	400	397,026	2,822,847	28,230

Appendix Table 9h

Land and Building Requirements

Total Number of Broodstock: 15
Marketing Strategy: 50 percent

Production Period	Land			Building and Roofing		
	Acres Required	Total Cost	Annual Tax	Square Feet Required	Total Cost	Annual Tax
		--------dollars--------			--------dollars--------	
Hatch production	0.03	94.92	1	1,378	34,450	345
Hatch to 1 month growout	0.03	89.54	1	1,300	32,500	325
1 to 3 month growout	1.16	3,478.44	35	50,500	1,262,500	12,625
3 month to 1 year growout	7.88	23,646.50	236	245,700	2,247,894	22,479
1 to 2 year growout	8.76	26,284.61	263	254,400	1,284,243	12,842
2 to 3 year growout	21.82	65,463.55	655	633,600	3,198,492	31,985
Office and lab building	0.07	206.64	2	2,400	139,872	1,399
Total	39.75	119,264.20	1,193	1,189,278	8,199,951	82,000

Appendix Table 9i

Land and Building Requirements

Total Number of Broodstock: 20
Marketing Strategy: 50 percent

Production Period	Land: Acres Required	Land: Total Cost	Land: Annual Tax	Building and Roofing: Square Feet Required	Building and Roofing: Total Cost	Building and Roofing: Annual Tax
		---------dollars---------			---------dollars---------	
Hatch production	0.04	120.82	1	1,754	43,850	439
Hatch to 1 month growout	0.04	117.10	1	1,700	42,500	425
1 to 3 month growout	1.55	4,649.40	46	67,500	1,687,500	16,875
3 month to 1 year growout	10.53	31,595.26	316	328,300	3,004,051	30,041
1 to 2 year growout	11.68	35,046.14	350	339,200	1,712,324	17,123
2 to 3 year growout	29.09	87,284.73	873	844,800	4,264,656	42,647
Office and lab building	0.07	206.64	2	2,400	139,872	1,399
Total	53.00	159,020.09	1,589	1,585,654	10,894,753	108,949

Appendix Table 9j

Joint Equipment Requirements

Total Number of Broodstock: 5
Marketing Strategy: 50 percent

Joint Equipment	Number Required for Years 1-10	Total Cost (dollars)
Emergency generator	1	48,237
Wells	5	324,014
Stripping towers	5	20,000
Office and laboratory equipment		10,000
Small tools		2,000
Trucks	2	22,500
Total		426,751

Appendix Table 9k

Joint Equipment Requirements

Total Number of Broodstock: 15
Marketing Strategy: 50 percent

Joint Equipment	Number Required for Years 1-10	Total Cost (dollars)
Emergency generator	1	108,264
Wells	15	968,280
Stripping towers	15	60,000
Office and laboratory equipment		10,000
Small tools		2,000
Trucks	2	22,500
Total		1,171,044

Appendix Table 9l

Joint Equipment Requirements

Total Number of Broodstock: 20
Marketing Strategy: 50 percent

Joint Equipment	Number Required for Years 1-10	Total Cost (dollars)
Emergency generator	1	143,808
Wells	20	1,290,414
Stripping towers	20	80,000
Office and laboratory equipment		10,000
Small tools		2,000
Trucks	2	22,500
Total		1,548,722

Appendix Table 9m

Annual Operating Costs

Total Number of Broodstock: 5
Marketing Strategy: 50 percent

Growout Period	Annual Operating Cost (dollars)
Hatch Production	
Fishing labor	432
Spawning labor	162
Fishing fuel	134
Pituitary extract	185
Water pumping	80
Water aeration	275
Maintenance	204
Total	1,472
Hatch to 1 Month Growout	
Larval labor	3,696
Larval feed	129
Water pumping	91
Water aeration	783
Maintenance	22
Total	4,721
1 to 3 Month Growout	
Fry labor	1,206
Fry feed	560
Water pumping	1,161
Water aeration	928
Autofeeder operation	193
Maintenance	650
Total	4,698
3 Month to 1 Year Growout	
Finger labor	1,926
Finger feed	14,458
Water pumping	13,156
Water aeration	14,426
Autofeeder operation	1,594
Maintenance	1,896
Total	47,456
1 to 2 Year Growout	
Labor	954
Feed	91,777
Water pumping	41,837
Water aeration	43,126
Autofeeder operation	2,709
Maintenance	1,673
Total	182,076
2 to 3 Year Growout	
Labor	2,376
Feed	231,304
Water pumping	96,683
Water aeration	97,109
Autofeeder operation	6,260
Maintenance	4,144
Total	437,876

Appendix Table 9n

Annual Operating Costs

Total Number of Broodstock: 15
Marketing Strategy: 50 percent

Growout Period	Annual Operating Cost (dollars)
Hatch Production	
Fishing labor	1,080
Spawning labor	486
Fishing fuel	336
Pituitary extract	554
Water pumping	239
Water aeration	276
Maintenance	236
Total	3,207
Hatch to 1 Month Growout	
Larval labor	11,088
Larval feed	388
Water pumping	272
Water aeration	2,349
Maintenance	40
Total	14,137
1 to 3 Month Growout	
Fry labor	3,636
Fry feed	1,679
Water pumping	3,549
Water aeration	2,783
Autofeeder operation	591
Maintenance	1,949
Total	14,187
3 Month to 1 Year Growout	
Finger labor	5,832
Finger feed	43,643
Water pumping	39,881
Water aeration	41,766
Autofeeder operation	4,822
Maintenance	5,775
Total	141,719
1 to 2 Year Growout	
Labor	2,862
Feed	275,337
Water pumping	126,242
Water aeration	126,166
Autofeeder operation	8,174
Maintenance	4,994
Total	543,775
2 to 3 Year Growout	
Labor	7,128
Feed	693,933
Water pumping	290,856
Water aeration	289,799
Autofeeder operation	18,833
Maintenance	12,431
Total	1,312,980

Appendix Table 9o

Annual Operating Costs

Total Number of Broodstock: 20
Marketing Strategy: 50 percent

Growout Period	Annual Operating Cost (dollars)
Hatch Production	
Fishing labor	1,512
Spawning labor	648
Fishing fuel	470
Pituitary extract	739
Water pumping	318
Water aeration	275
Maintenance	252
Total	4,214
Hatch to 1 Month Growout	
Larval labor	14,784
Larval feed	517
Water pumping	363
Water aeration	3,132
Maintenance	49
Total	18,845
1 to 3 Month Growout	
Fry labor	4,860
Fry feed	2,239
Water pumping	4,732
Water aeration	3,579
Autofeeder operation	788
Maintenance	2,598
Total	18,796
3 Month to 1 Year Growout	
Finger labor	7,776
Finger feed	58,192
Water pumping	53,225
Water aeration	55,754
Autofeeder operation	6,435
Maintenance	7,709
Total	189,091
1 to 2 Year Growout	
Labor	3,816
Feed	367,118
Water pumping	168,463
Water aeration	168,221
Autofeeder operation	10,908
Maintenance	6,655
Total	725,181
2 to 3 Year Growout	
Labor	9,504
Feed	925,247
Water pumping	387,924
Water aeration	386,449
Autofeeder operation	25,118
Maintenance	16,575
Total	1,750,817

Appendix Table 10a

Production Under a 10 Percent Marketing Strategy[a] (Per Cohort of Fish)

Number of Broodstock: 10

Age	Body Weight (grams/fish)	Number Produced	Number Sold	Production[b] (kg)
Hatchling	0.016[c]	808,582	80,858	11.64
1 month	0.19	457,213	45,721	78.18
3 months	19.08	307,872	30,787	5,286.78
6 months	102.60	277,041	0	28,424.41
12 months	537.32	277,041	0	148,859.67
18 months	1,415.41	277,041	0	392,126.60
24 months	2,814.08	277,041	0	779,615.54
30 months	4,795.52	277,041	0	1,328,555.66
36 months	7,412.82	277,041	277,041	2,053,655.07

[a]For all stages after hatch, the number produced takes into account mortality and any previous production sold.
[b]Production retained for continued culture or sold at the end of 36 months growout.
[c]Based on mean weight of 12 larvae at hatch (Beer, 1981).

Appendix Table 10b

Production Under a 25 Percent Marketing Strategy[a] (Per Cohort of Fish)

Number of Broodstock: 10

Age	Body Weight (grams/fish)	Number Produced	Number Sold	Production[b] (kg)
Hatchling	0.016[c]	808,582	202,146	9.70
1 month	0.19	381,012	95,253	54.29
3 months	19.08	213,800	53,450	3,059.48
6 months	102.60	160,324	0	16,449.34
12 months	537.32	160,324	0	86,145.83
18 months	1,415.41	160,324	0	226,925.61
24 months	2,814.08	160,324	0	451,167.38
30 months	4,795.52	160,324	0	768,841.74
36 months	7,412.82	160,324	160,324	1,188,460.37

[a]For all stages after hatch, the number produced takes into account mortality and any previous production sold.
[b]Production retained for continued culture or sold at the end of 36 months growout.
[c]Based on mean weight of 12 larvae at hatch (Beer, 1981).

Appendix Table 10c

Production Under a 75 Percent Marketing Strategy[a] (Per Cohort of Fish)

Number of Broodstock: 10

Age	Body Weight (grams/fish)	Number Produced	Number Sold	Production[b] (kg)
Hatchling	0.016[c]	808,582	606,437	3.23
1 month	0.19	127,003	95,252	6.03
3 months	19.08	23,754	17,816	3,190.07
6 months	102.60	5,937	0	609.14
12 months	537.32	5,937	0	3,190.07
18 months	1,415.41	5,937	0	8,403.29
24 months	2,814.08	5,937	0	16,707.19
30 months	4,795.52	5,937	0	28,471.00
36 months	7,412.82	5,937	5,937	44,009.91

[a]For all stages after hatch, the number produced takes into account mortality and any previous production sold.
[b]Production retained for continued culture or sold at the end of 36 months growout.
[c]Based on mean weight of 12 larvae at hatch (Beer, 1981).

Appendix Table 10d

Production Under a 90 Percent Marketing Strategy[a] (Per Cohort of Fish)

Number of Broodstock: 10

Age	Body Weight (grams/fish)	Number Produced	Number Sold	Production[b] (kg)
Hatchling	0.016[c]	808,582	727,724	1.29
1 month	0.19	50,801	45,721	0.97
3 months	19.08	3,800	3,420	7.25
6 months	102.60	379	0	0.04
12 months	537.32	379	0	0.20
18 months	1,415.41	379	0	0.54
24 months	2,814.08	379	0	1.07
30 months	4,795.52	379	0	18.17
36 months	7,412.82	379	379	28.09

[a]For all stages after hatch, the number produced takes into account mortality and any previous production sold.
[b]Production retained for continued culture or sold at the end of 36 months growout.
[c]Based on mean weight of 12 larvae at hatch (Beer, 1981).

Appendix Table 10e

Equipment Requirements

Total Number of Broodstock: 10
Marketing Strategy: 10 percent

Equipment	Number Required for Years 1-10	Total Cost (dollars)
Production Stage I		
Boat	1	16,000
Fishing nets	30	15,000
Fish hauler	1	1,100
Brood tanks	4	6,380
Incubation system	1	3,600
Aeration system	1	1,972
Total		44,052
Production Stage II		
Larval tanks	15	6,750
Freezer	1	600
Aeration system	1	1,622
Total		8,972
Production Stage III		
12-foot diameter tanks	437	426,075
Automatic feeders	874	301,530
Aeration system	55	113,245
Total		840,850
Production Stage IV		
12-foot diameter tanks	1,137	1,108,575
30-foot diameter tanks	2,635	13,175,000
Automatic feeders	7,544	2,602,680
Aeration system (12-foot tanks)	142	292,378
Aeration system (30-foot tanks)	659	1,550,627
Total		18,729,260

Appendix Table 10f

Equipment Requirements

Total Number of Broodstock: 10
Marketing Strategy: 25 percent

Equipment	Number Required for Years 1-10	Total Cost (dollars)
Production Stage I		
Boat	1	16,000
Fishing nets	30	15,000
Fish hauler	1	1,100
Brood tanks	4	6,380
Incubation system	1	3,600
Aeration system	1	1,972
Total		44,052
Production Stage II		
Larval tanks	13	5,850
Freezer	1	600
Aeration system	1	1,622
Total		8,072
Production Stage III		
12-foot diameter tanks	304	296,400
Automatic feeders	608	209,760
Aeration system	38	78,242
Total		584,402
Production Stage IV		
12-foot diameter tanks	606	590,850
30-foot diameter tanks	1,525	7,625,000
Automatic feeders	4,262	1,470,390
Aeration system (12-foot tanks)	76	156,484
Aeration system (30-foot tanks)	382	898,846
Total		11,741,570

Appendix Table 10g

Equipment Requirements

Total Number of Broodstock: 10
Marketing Strategy: 75 percent

Equipment	Number Required for Years 1-10	Total Cost (dollars)
Production Stage I		
Boat	1	16,000
Fishing nets	30	15,000
Fish hauler	1	1,100
Brood tanks	4	6,380
Incubation system	1	3,600
Aeration system	1	1,972
Total		44,052
Production Stage II		
Larval tanks	5	2,250
Freezer	1	600
Aeration system	1	1,622
Total		4,472
Production Stage III		
12-foot diameter tanks	33	32,175
Automatic feeders	66	22,770
Aeration system	5	10,295
Total		65,240
Production Stage IV		
12-foot diameter tanks	0	0
30-foot diameter tanks	56	280,000
Automatic feeders	112	38,640
Aeration system (12-foot tanks)	0	0
Aeration system (30-foot tanks)	14	32,942
Total		351,582

Appendix Table 10h

Equipment Requirements

Total Number of Broodstock: 10
Marketing Strategy: 90 percent

Equipment	Number Required for Years 1-10	Total Cost (dollars)
Production Stage I		
Boat	1	16,000
Fishing nets	30	15,000
Fish hauler	1	1,100
Brood tanks	4	6,380
Incubation system	1	3,600
Aeration system	1	1,972
Total		44,052
Production Stage II		
Larval tanks	2	900
Freezer	1	600
Aeration system	1	1,622
Total		3,122
Production Stage III		
12-foot diameter tanks	5	4,875
Automatic feeders	10	3,450
Aeration system	1	2,059
Total		10,384
Production Stage IV		
12-foot diameter tanks	0	0
30-foot diameter tanks	2	10,000
Automatic feeders	4	1,380
Aeration system (12-foot tanks)	0	0
Aeration system (30-foot tanks)	1	2,353
Total		13,733

Appendix Table 10i

Joint Equipment Requirements

Total Number of Broodstock: 10
Marketing Strategy: 10 percent

Joint Equipment	Number Required for Years 1-10	Total Cost (dollars)
Emergency generator	1	417,876
Wells	58	3,732,416
Stripping towers	58	232,000
Office and laboratory equipment		10,000
Small tools		2,000
Trucks	2	22,500
Total		4,416,792

Appendix Table 10j

Joint Equipment Requirements

Total Number of Broodstock: 10
Marketing Strategy: 25 percent

Joint Equipment	Number Required for Years 1-10	Total Cost (dollars)
Emergency generator	1	242,400
Wells	34	2,178,055
Stripping towers	34	136,000
Office and laboratory equipment		10,000
Small tools		2,000
Trucks	2	22,500
Total		2,590,955

Appendix Table 10k

Joint Equipment Requirements

Total Number of Broodstock: 10
Marketing Strategy: 75 percent

Joint Equipment	Number Required for Years 1-10	Total Cost (dollars)
Emergency generator	1	18,538
Wells	2	109,366
Stripping towers	2	8,000
Office and laboratory equipment		10,000
Small tools		2,000
Trucks	2	22,500
Total		170,404

Appendix Table 10l

Joint Equipment Requirements

Total Number of Broodstock: 10
Marketing Strategy: 90 percent

Joint Equipment	Number Required for Years 1-10	Total Cost (dollars)
Emergency generator	1	5,125
Wells	1	23,179
Stripping towers	1	4,000
Office and laboratory equipment		10,000
Small tools		2,000
Trucks	2	22,500
Total		66,804

Appendix Table 10m

Annual Operating Costs

Total Number of Broodstock: 10
Marketing Strategy: 10 percent

Growout Period	Annual Operating Cost (dollars)
Hatch Production	
Fishing labor	864
Spawning labor	324
Fishing fuel	269
Pituitary extract	370
Water pumping	159
Water aeration	275
Maintenance	220
Total	2,481
Hatch to 1 Month Growout	
Larval labor	13,398
Larval feed	466
Water pumping	327
Water aeration	2,819
Maintenance	45
Total	17,055
1 to 3 Month Growout	
Fry labor	7,866
Fry feed	3,627
Water pumping	7,690
Water aeration	5,787
Autofeeder operation	1,280
Maintenance	4,204
Total	30,454
3 Month to 1 Year Growout	
Finger labor	29,016
Finger feed	169,687
Water pumping	155,391
Water aeration	161,125
Autofeeder operation	18,786
Maintenance	25,841
Total	559,846
1 to 2 Year Growout	
Labor	11,160
Feed	1,070,518
Water pumping	491,958
Water aeration	489,981
Autofeeder operation	31,855
Maintenance	19,463
Total	2,114,935
2 to 3 Year Growout	
Labor	27,720
Feed	2,698,025
Water pumping	1,131,865
Water aeration	1,125,091
Autofeeder operation	73,289
Maintenance	48,343
Total	5,104,333

Appendix Table 10a

Annual Operating Costs

Total Number of Broodstock: 10
Marketing Strategy: 25 percent

Growout Period	Annual Operating Cost (dollars)
Hatch Production	
Fishing labor	864
Spawning labor	324
Fishing fuel	269
Pituitary extract	370
Water pumping	159
Water aeration	275
Maintenance	220
Total	2,481
Hatch to 1 Month Growout	
Larval labor	11,088
Larval feed	388
Water pumping	272
Water aeration	2,349
Maintenance	40
Total	14,137
1 to 3 Month Growout	
Fry labor	5,472
Fry feed	2,519
Water pumping	5,331
Water aeration	4,064
Autofeeder operation	887
Maintenance	2,922
Total	21,195
3 Month to 1 Year Growout	
Finger labor	15,858
Finger feed	98,199
Water pumping	89,863
Water aeration	93,684
Autofeeder operation	10,865
Maintenance	14,463
Total	322,932
1 to 2 Year Growout	
Labor	6,462
Feed	619,514
Water pumping	284,544
Water aeration	283,376
Autofeeder operation	18,425
Maintenance	11,272
Total	1,223,593
2 to 3 Year Growout	
Labor	16,038
Feed	1,561,360
Water pumping	654,840
Water aeration	651,473
Autofeeder operation	42,402
Maintenance	27,973
Total	2,954,086

Appendix Table 10o

Annual Operating Costs

Total Number of Broodstock: 10
Marketing Strategy: 75 percent

Growout Period	Annual Operating Cost (dollars)
Hatch Production	
Fishing labor	864
Spawning labor	324
Fishing fuel	269
Pituitary extract	370
Water pumping	159
Water aeration	275
Maintenance	220
Total	2,481
Hatch to 1 Month Growout	
Larval labor	3,696
Larval feed	129
Water pumping	91
Water aeration	783
Maintenance	22
Total	4,721
1 to 3 Month Growout	
Fry labor	594
Fry feed	280
Water pumping	562
Water aeration	574
Autofeeder operation	93
Maintenance	326
Total	2,429
3 Month to 1 Year Growout	
Finger labor	180
Finger feed	3,636
Water pumping	3,175
Water aeration	3,990
Autofeeder operation	386
Maintenance	320
Total	11,687
1 to 2 Year Growout	
Labor	234
Feed	22,941
Water pumping	10,238
Water aeration	11,164
Autofeeder operation	663
Maintenance	405
Total	45,645
2 to 3 Year Growout	
Labor	594
Feed	57,819
Water pumping	23,940
Water aeration	24,621
Autofeeder operation	1,550
Maintenance	1,033
Total	109,557

Appendix Table 10p

Annual Operating Costs

Total Number of Broodstock: 10
Marketing Strategy: 90 percent

Growout Period	Annual Operating Cost (dollars)
Hatch Production	
Fishing labor	864
Spawning labor	324
Fishing fuel	269
Pituitary extract	370
Water pumping	159
Water aeration	275
Maintenance	220
Total	2,481
Hatch to 1 Month Growout	
Larval labor	1,386
Larval feed	52
Water pumping	36
Water aeration	313
Maintenance	16
Total	1,803
1 to 3 Month Growout	
Fry labor	90
Fry feed	45
Water pumping	75
Water aeration	177
Autofeeder operation	12
Maintenance	52
Total	451
3 Month to 1 Year Growout	
Finger labor	0
Finger feed	233
Water pumping	60
Water aeration	309
Autofeeder operation	10
Maintenance	0
Total	612
1 to 2 Year Growout	
Labor	18
Feed	1,464
Water pumping	308
Water aeration	1,223
Autofeeder operation	20
Maintenance	40
Total	3,073
2 to 3 Year Growout	
Labor	18
Feed	3,691
Water pumping	1,155
Water aeration	2,753
Autofeeder operation	75
Maintenance	28
Total	7,720

Appendix Table 10q

Annual Joint Equipment Depreciation Costs

Total Number of Broodstock: 10
Marketing Strategy: 75 percent

Joint Equipment	Year of Operation 1	2	3	4	5	6	7	8	9	10
	dollars									
Emergency generator	2,642	3,874	3,698	3,698	3,698	0	0	0	0	0
Wells	10,390	11,429	9,351	8,312	7,273	6,234	6,234	6,234	6,234	5,195
Stripping towers	760	836	684	608	532	456	456	456	456	380
Office and lab building	13,987	15,386	12,588	11,190	9,791	8,392	8,392	8,392	8,392	6,994
Office and lab equipment	1,425	2,090	1,995	1,995	1,995	0	0	0	0	0
Small tools	285	418	399	399	399	0	0	0	0	0
Trucks (2)	5,625	8,550	8,325	0	0	0	0	0	0	0
Total	35,114	42,583	37,040	26,202	23,688	15,082	15,082	15,082	15,082	12,569

Appendix Table 10r

Annual Joint Equipment Depreciation Costs

Total Number of Broodstock: 10
Marketing Strategy: 90 percent

Joint Equipment	Year of Operation									
	1	2	3	4	5	6	7	8	9	10
	dollars									
Emergency generator	730	1,071	1,022	1,022	1,022	0	0	0	0	0
Wells	2,202	2,422	1,982	1,762	1,541	1,321	1,321	1,321	1,321	1,101
Stripping towers	380	418	342	304	266	228	228	228	228	190
Office and lab building	13,987	15,386	12,588	11,190	9,791	8,392	8,392	8,392	8,392	6,994
Office and lab equipment	1,425	2,090	1,995	1,995	1,995	0	0	0	0	0
Small tools	285	418	399	399	399	0	0	0	0	0
Trucks (2)	5,625	8,550	8,325	0	0	0	0	0	0	0
Total	24,634	30,355	26,653	16,672	15,014	9,941	9,941	9,941	9,941	8,285