CHAPTER 7

ECONOMIC FEASIBILITY & IMPACT OF OFFSHORE AQUACULTURE IN THE GULF OF MEXICO[1]

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ABSTRACT

An offshore aquaculture industry in the Gulf of Mexico will never exist if this innovative business venture does not make economic sense. To more fully understand the economic potential of offshore aquaculture, that can also be effectively managed as determined by OAC researchers, we created a model to analyze the OAC hypothetical offshore aquaculture production system. This model is based on present expectations of technology and logistics mitigation of offshore growout, biology of suitable species, recommended usage and costs of inputs, and established ex-vessel fish prices. Simulation results of each candidate species (i.e., cobia, red snapper, and red drum), with enhanced market value and improved growth rates over wild fishery data, and twelve cages having fish stocked at 30 kg/m^3 indicated a favorable investment project with positive net present value and internal rates of return. Given these favorable results, we conducted further economic analyses to determine the potential economic impact of an offshore aquaculture industry on the local economy. The operation of a 12-cage offshore production system would produce an additional annual regional economic output reaching more than U.S. $9 million and provide additional employment for at least 262 persons.

INTRODUCTION

Total seafood consumption has been steadily growing in the U.S. Even if per capita consumption remained unchanged at 6.8 kg/yr, a 1% increase in the U.S. population growth alone would add more than 18 x 10^6 kg to the demand for seafood each year. The domestic fishery can no longer supply additional landings of most wild caught species without endangering the resources. Increases in domestic demand will have to be met either through increased aquaculture production or increased imports. More than 2/3 of the seafood consumed in the U.S. is imported resulting in more than U.S. $8 billion deficit in the nation's seafood trade balance (USDC 2003). Many species heavily imported are currently being overexploited worldwide causing further need to become dependent on domestic aquaculture production.

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Economic benefits from aquaculture production accrue not only to those directly involved in the industry but contribute to increased employment and revenue of the entire region through multiplier effects. Aquaculture can also supplement domestic fisheries, increase seafood production, and provide stability for the seafood industry. A successful approach to solving many present domestic fishery problems is through the development of intensive aquaculture programs in the United States, such as the farm raised catfish industry centered in the Mississippi Delta region. Aquaculture has been established in the U.S. for more than 100 yr, but it remains relatively undeveloped in comparison to the rest of the world. While farmed seafood contributes more than 25% by weight to world seafood production, U.S. production is less than 3% of world aquaculture production. In recent years, however, U.S. production has grown to more than 371,000 metric tons (mt; USDC 2003).

Coastal and offshore aquaculture frequently involves new species, product forms, and production technologies. During the last decade, several species have been raised along the Gulf of Mexico including catfish, baitfish, gamefish, soft shell crab, crawfish, red drum, hybrid striped bass, tilapia, alligators, freshwater prawns, oysters, and carp. Because research and development efforts have been focused on production, little attention has been paid to linking aquaculture with existing support services or to developing needed infrastructure. Essential seafood services such as processing, storage, transportation, financing, insurance, and personnel training already exist in the coastal region.

Determination of cost projections for offshore aquaculture production systems is useful to determine the viability of such operations under present and future economic conditions. Information on production costs allows economists and scientists to discuss major contributing cost factors with a goal of focusing future research efforts toward reducing these costs and increasing profitability. Engle (1989) stated that profitability is difficult to measure for new technologies not yet adopted on a commercial scale. It is precisely at this point in the development of an innovation, however, that information relative to the economics of the new technology is most useful. Cost estimation provides information on the production efficiency of the new technology and as a base for future comparisons. Careful assessment of benefits arising from the new technology leads to the estimation of potential revenues. Once the benefits and costs associated with the new technology are determined, revenues can be compared with costs by using enterprise budgets (Posadas and Dillard 1997; Posadas 2000). The profit motive of fish farmers to adopt a technology would be met if the expected marginal benefits were equal to the estimated marginal costs of constructing and operating new systems. Every fish farmer, lender, and investor is concerned with the employment of scarce capital to its most productive use.

Our economic research efforts have focused on the potential of offshore aquaculture of candidate finfish species in the Gulf of Mexico. Specifically, we attempted to determine the:

1. economic feasibility of offshore aquaculture in the Gulf of Mexico at the individual farm scale under different economic and biological scenarios;

2. economic impact of an emerging offshore aquaculture industry and existing

fish harvesting and processing industry on the regional economy; and,

3. most efficient means to transport commercial quantities of fingerlings to a distant offshore aquaculture site from an economic perspective.

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Methods

A hypothetical commercial offshore aquaculture production system (COAPS) is constructed based on present information of offshore grow-out technology and biology of suitable species in the Gulf of Mexico. Numerous researchers have indicated that existing oil and gas structures may be utilized for open ocean aquaculture platforms (Stickney 1999). Owing to expected constraints (i.e., dependence, sub-optimal structure, liability, cost, and inappropriate site selection for aquaculture), however, an alternative approach should be considered for the future of offshore aquaculture in the Gulf of Mexico (Bridger and Goudey, this volume). Therefore, the hypothetical offshore fish farm presented consists of an Aquaculture Support Vessel (ASV) and appropriate offshore cages. The ASV, which is presently under consideration, is envisioned as a mobile offshore support structure that can be used to adjust deployment of the sea cages. It may also serve as offshore quarters for the crew (1 supervisor and 3 farm crew/shift), storage for feed and supplies, and transport for fish to be harvested.

Based on present OAC experience, the 3000-m^3 cages are deployed 40 km offshore, in water at least 24 m deep, and able to hold 20–30 kg/m^3 of market-size fish (Bridger and Costa-Pierce 2002). The base model scenario has six cages. Two service boats are used at the offshore farm for daily operations, maintenance, and harvesting. A supply boat and crew are hired to transport fingerlings, farm crew, and supplies, on an operation determined basis. Initially, fingerlings are purchased from commercial nurseries located within the region, which in the future may be integrated in the aquaculture operation. Slow sinking marine species feed is bought in bulk from nearby commercial feed manufacturing plants. An additional harvesting crew is employed to harvest fish from each cage on a regular basis. Office staff (1 manager and 2 office staff) housed in a building located in a 0.8-hectare land-based facility undertakes initial marketing of fish.

An enterprise budget is created for the hypothetical base COAPS, including investment requirements, operating costs, and net returns. Initial investment requirements for COAPS are based on OAC scientist and industrial partner specifications. Total costs of COAPS include both operating and ownership costs. Operational expenditures are based on estimated input usage and costs. Input usage is based on recommended management practices and biological knowledge of candidate finfish species. Ownership costs include depreciation, investment interest, management, and insurance for fish stock and equipment. For the hypothetical base model using six offshore cages (BASE6), gross returns are estimated from the average established ex-vessel prices of all candidate finfish species combined and expected annual yields. Candidate species considered are red drum (*Sciaenops ocellatus*), red snapper (*Lutjanus campechanus*), and cobia (*Rachycentron canadum*). The BASE6 cages are stocked with 10-g fingerlings to give a final stocking density of 20 and 30 kg/m^3 of market-sized fish in

9 mo. Deviations from this base model included specific candidate species models using 6 and 12 cages/operation, increasing the price by \$1/kg over the established ex-vessel price of each candidate species, improving fish growth through optimal farm management, and combined growth improvement and price increase scenarios. Presently, provisions for the costs of the permitting process and environmental monitoring are not included in the model. Further, the logistical problem of transporting feed and market-size fish has not been adequately examined at this stage. A comparison of three methods to transport fingerlings is provided below. Net returns from all COAPS simulations consisted of the difference between gross returns and total costs.

Investment analysis provides a mechanism for comparing alternative investment opportunities (Gittinger 1982; Robison and Barry 1996). It is recognized, however, that it will be difficult to extrapolate experimental data for purposes of doing investment analysis of hypothetical commercial-scale fish farming operations (Posadas 1998). A wide range of risks is involved in grow-out culture in the Gulf of Mexico associated with the uncertainty in output and prices. Output risks may include complete or partial loss of the crop due to natural disasters (e.g., hurricanes), poor survival, slow growth, lack of fingerlings, and technical malfunction. Risks associated with prices may arise from competition with wild harvests, imports, and land-based production. It is important to recognize that at this stage of offshore technology development, the various risks involved need to be managed in order to reduce their negative effects on the economic viability of this emerging industry.

In order to determine the economic viability of base COAPS models and their derivatives, three investment indicators are evaluated under different critical technical, biological, and economic scenarios. The net present value (NPV) is the sum of the discounted annual net benefits of an investment project (Shang 1990). If NPV > 0, the project is economically feasible; it is not feasible if NPV < 0; and, it is a break-even situation if NPV = 0 (Shang 1990). Internal rate of return (IRR) is the discount rate that makes the present value of the annual net benefits of an investment project equal to zero (Shang 1990). The decision rule used in determining the economic feasibility of an investment project using the IRR method is as follows: if IRR ≥ cost of capital (r), accept the project; otherwise, reject the project (Shang 1990). The payback period (PP) estimates the number of years to recover the initial investment out of the expected annual net income before any allowance for depreciation (Shang 1990).

Results and Discussion

Three candidate finfish species are considered for culture in the hypothetical COAPS. Cobia (*Rachycentron canadum*) has been successfully cultured in ponds and cages in Taiwan and can be grown to 7 kg in one year (I-Chiu Liao, Director General, Taiwan Fisheries Research Institute, personal communication). Phelps et al. (2000) showed that red snapper (*Lutjanus campechanus*) grew at a rate of 1.23 g/d in experimental 0.051 m^3 cages located in Gulf Shores, Alabama. Red drum (*Sciaenops ocellatus*) has been cultured in ponds and offshore cages in the Gulf of Mexico and reached 1 kg in 12 mo (Holt 2000).

The initial enterprise budget model (BASE6) for the hypothetical COAPS requires an initial fixed investment of \$2.89 x 10^6 consisting of \$1.50 x 10^6 for the ASV, \$0.96 x 10^6 for six cages/mooring and associated equipment (i.e., net cleaners), \$0.33 x

Table 1. Initial fixed investment in a base COAPS with 6-cages.

Item	Total Cost ($)	Per m^3 ($)	% of Total
Land and Permitting			
Land, base camp	80,000	4	3%
Sub-total	80,000	4	3%
Onshore Support Facilities			
Buildings, trailers	100,000	6	3%
Trucks/Service vehicle	50,000	3	2%
Fish transport vehicle	100,000	6	3%
Sub-total	250,000	14	9%
Offshore Operations			
Cages[1], moorings, feed distribution	900,000	50	31%
Aquaculture Service Vehicle	1,500,000	83	52%
Net cleaners	60,000	3	2%
Vessel (> 50', small outboard)	100,000	6	3%
Sub-total	2,560,000	142	89%
TOTAL	2,890,000	161	100%

[1]growing area is 3,000 m^3/cage.

10^6 for land and onshore support facilities, and \$0.10 x 10^6 for service vessels (Table 1). On average, initial fixed investment on a COAPS is \$161/m^3 of growing area. With stocking density of 30 kg/m^3, an operating capital of \$1.28 x 10^6 is needed to finance the cost of repair and maintenance, fuel and oil, fingerlings, feed, labor, supply boat and crew, harvesting and hauling, liability insurance, and miscellaneous expenses (Table 2).

Given the base model assumptions, an estimated 0.54 x 10^6 kg, 2.11-kg fish can be produced every 9-mo of offshore grow-out period. The estimated average cost of production is \$4.286/kg, consisting of \$2.641 and \$1.645/kg average variable and fixed costs, respectively. The major cost items are labor (22%), feed (20%), fingerlings (17%), repair and maintenance (13%), and supply boat (10%) for operating costs; and, depreciation (42%), farm management (25%), insurance on fish stocks and equipment (17%), and interest on investment (16%) for fixed costs (Table 2). At an average established ex-vessel price of \$4.25/kg whole, fresh on ice, annual net return is \$–0.02 x 10^6, payback period is indefinite, and net present value and internal rate of return are negative for the BASE6 model using 30 kg/m^3 stocking density (Table 3). A lower stocking assumption of 20 kg/m^3 produced similar economically unfavorable simulation results.

The BASE6 scenario can be considered as a benchmark for further economic and environmental analysis of COAPS under different technical, biological, and economic circumstances. At gross feed conversion (FCR) of 1.5:1.0, estimated total feed consumption was 0.54 and 0.81 thousand metric tons/crop for the 20 and 30 kg/m^3 stocking densities, respectively. The number of fingerlings needed was 213.66 and 320.40 thousand pieces/crop for the 20 and 30 kg/m^3 stocking densities, respectively.

Species-specific evaluations were generated by applying best available information on growth rate and established ex-vessel price of

Table 2. Total annual costs and returns of a base COAPS[1] with 6 cages using stocking density of 30 kg/m^3.

Item	Total Cost ($)	Per m^3 ($)	Per kg ($)	% of Total
Gross receipts	2,297,952	766	4.255	
Variable Costs				
Repair and maintenance	188,500	63	0.349	13%
Fuel & oil	30,000	10	0.056	2%
Fingerlings	240,300	80	0.445	17%
Feed	283,537	95	0.525	20%
Labor	312,500	104	0.579	22%
Harvesting & hauling	47,626	16	0.088	3%
Liability insurance	30,000	10	0.056	2%
Supply boat	144,000	48	0.267	10%
Miscellaneous	54,000	18	0.100	4%
Operating interest	95,735	32	0.177	7%
Total variable costs	1,426,197	475	2.641	100%
Income above variable costs	871,754	291	1.614	
Fixed Costs				
Depreciation	377,000	126	0.698	42%
Farm management	218,750	73	0.405	25%
Interest on investment	144,500	48	0.268	16%
Insurance on stocks & equipment	148,118	49	0.274	17%
Total fixed costs	888,368	296	1.645	100%
Total Costs	2,314,565	772	4.286	
Net Returns	(16,614)	(6)	(0.031)	

1- stocking size - 10 g/fish; stocking density - 17.8 fish/m^3; growth rate - 233 g/mo; gross feed conversion - 1.5 kg of feed per kg of fish; survival rate - 80%; capital outlay - $2.89 M; ex-vessel price - $4.25/kg; grow-out period - 9 mo; harvest size - 2.11 kg/fish.

the three candidate finfish species to the BASE6 model. Simulation results using both stocking densities, 20 and 30 kg/m^3, showed that none of the three species has economic potential (Table 4). Since it is still under development, it is assumed that one ASV unit can adequately provide support services to 12 offshore cages and accommodate 12 persons during regular aquaculture and rotating harvesting operations. With 12 offshore cages, the average initial fixed investment decreases accordingly to $107/m^3 of growing area. By expanding growing capacity to 12 cages/operation, simulation results using the higher stocking density indicated that cobia is an economically viable species for offshore culture in the Gulf of Mexico (Table 5).

The culture of red snapper and red drum using commercial offshore cages and the ASV in the Gulf of Mexico is not economically feasible given the current biological information, cost structure of the offshore production technology, and established ex-vessel market prices of the selected species. Both base and expanded model simulation results indicated that the two proposed investment projects are not favorable (PP = indefinite, IRR < 0 and NPV < 0; Tables 4 and 5).

The economic and biological constraints to finfish offshore aquaculture in the Gulf of Mexico could be adequately managed to promote the growth of this emerging industry. Economic feasibility of offshore grow-out of

Table 3. Simulation results of base COAPS model with 6 cages (BASE6) using two stocking densities.

Item	Unit	20 kg/m^3	30 kg/m^3
Model Assumptions[1]			
Stocking density	fish/m^3	11.87	17.80
Model Description			
Harvest size	kg/fish	2.11	2.11
Fingerlings required	1,000 pc	213.66	320.40
Fish production	1,000 mt	0.36	0.54
Feed required	1,000 mt	0.54	0.81
Model Results			
Net returns	$M	(0.55)	(0.02)
Payback period	yr	∝	∝
NPV	$M	< 0	< 0
IRR	%	< 0	< 0
Investment Decision		Infeasible	Infeasible

1- stocking size - 10 g/fish; growth rate - 233 g/mo; gross feed conversion - 1.5 kg of feed per kg of fish; survival rate - 80%; capital outlay - $2.89 M; ex-vessel price - $4.25/kg; grow-out period - 9 mo.

the selected species can be enhanced by a combination of revenue-enhancing and cost-reducing measures, including improvement in fish growth and market development. Changes in ex-vessel prices influence the economic feasibility of offshore aquaculture in the Gulf of Mexico. The most recent reported commercial landings of red drum, red snapper, and cobia in the Gulf of Mexico were valued at an average ex-vessel price of $3.75, $4.50, and $4.25/kg, respectively.

Simulation results of the ENHANCED MARKET models led to mixed investment decisions should prices received be $1.00/kg higher than the reported ex-vessel prices, *ceteris paribus*. The ENHANCED MARKET base model results indicated that only the proposed 6-cage COAPS at higher stocking density for cobia in the Gulf of Mexico would be economically feasible (Table 6). Simulation results on the ENHANCED MARKET base models for red snapper and red drum, however, indicated that the use of the proposed 6-cage COAPS for these species would not be economically viable (Table 6). With expanded growing capacity of 12-cages/operation, all three species have the potential of being economically viable at the higher ex-vessel price ($1.00/kg more) and higher stocking density (30 kg/m^3; Table 7).

A moderate improvement (25%) in fish growth rate does not have any significant effects on the economic viability of the offshore culture of the three species in the Gulf of Mexico, *ceteris paribus*. An increase in fish growth rates by 25% and the corresponding reduction in stocking density in order to maintain the maximum biomass of market-size fish at 20 and 30 kg/m^3, *ceteris paribus*, is not sufficient to enhance economic performance of the 6-cage COAPS as shown by the simulation results of the IMPROVED GROWTH models (Table 8). The expansion of the growing capacity to 12 cages/operation at both stocking densities did not improve the economic potential of red snapper and red drum grow-out culture in the Gulf of Mexico (Table 9).

The combined effects of IMPROVED GROWTH and ENHANCED MARKET models on the aquaculture of individual candidate

Table 4. Simulation results of COAPS candidate species base models with 6 cages (SPECIES6) using two stocking densities.

Item	Unit	COBIA6		SNAP6		DRUM6	
		20 kg/m^3	30 kg/m^3	20 kg/m^3	30 kg/m^3	20 kg/m^3	30 kg/m^3
Model Assumptions[1]							
Stocking density	fish/m^3	4.75	7.13	55.06	82.60	27.49	41.24
Growth rate	g/mo	583.00	583.00	37.00	37.00	80.00	80.00
Ex-vessel price	$/kg	4.25	4.25	4.50	4.50	3.75	3.75
Model Description							
Harvest size	kg/fish	5.25	5.25	0.45	0.45	0.97	0.97
Fingerlings used	1,000 pc	85.00	128.34	991.08	1,468.80	494.82	742.23
Fish production	1,000 mt	0.36	0.54	0.36	0.54	0.36	0.54
Feed required	1,000 mt	0.54	0.81	0.54	0.81	0.54	0.81
Model Results							
Net returns	$M	(0.65)	(0.17)	(0.20)	(0.95)	(1.05)	(0.73)
Payback period	yr	∝	∝	∝	∝	∝	∝
NPV	$M	<0	<0	<0	<0	<0	<0
IRR	%	<0	<0	<0	<0	<0	<0
Investment Decision		Infeasible	Infeasible	Infeasible	Infeasible	Infeasible	Infeasible

1- stocking size - 10 g/fish; gross feed conversion - 1.5 kg of feed per kg of fish; survival rate - 80%; capital outlay - $2.89 M; grow-out period - 9 mo for cobia and 12 mo for red snapper and red drum.

Table 5. Simulation results of COAPS candidate species expanded models with 12 cages (SPECIES12) using two stocking densities.

Item	Unit	COBIA12		SNAP12		DRUM12	
		20 kg/m^3	30 kg/m^3	20 kg/m^3	30 kg/m^3	20 kg/m^3	30 kg/m^3
Model Assumptions[1]							
Stocking density	fish/m^3	4.75	7.13	55.06	82.60	27.49	41.24
Growth rate	g/mo	583.00	583.00	37.00	37.00	80.00	80.00
Ex-vessel price	$/kg	4.25	4.25	4.50	4.50	3.75	3.75
Model Description							
Harvest size	kg/fish	5.25	5.25	0.45	0.45	0.97	0.97
Fingerlings used	1,000 pc	171.00	256.68	1,982.16	2,973.60	989.64	1,484.46
Fish production	1,000 mt	0.72	1.08	0.72	1.08	0.72	1.08
Feed required	1,000 mt	1.08	1.62	1.08	1.62	1.08	1.62
Model Results							
Net returns	$M	(0.13)	0.83	(1.14)	(0.64)	(0.84)	(0.19)
Payback period	yr	∝	4.70	∝	∝	∝	∝
NPV $M	<0	3.17	<0	<0	<0	<0	
IRR %	<0	29.24	<0	<0	<0	<0	
Investment Decision		Infeasible	**Feasible**	Infeasible	Infeasible	Infeasible	Infeasible

1- stocking size - 10 g/fish; gross feed conversion - 1.5 kg of feed per kg of fish; survival rate - 80%; capital outlay - $3.85 M; grow-out period - 9 mo for cobia and 12 mo for red snapper and red drum.

Table 6. Simulation results of COAPS candidate species ENHANCED MARKET base models with 6 cages using two stocking densities.

		COBIA6		SNAP6		DRUM6	
Item	**Unit**	**20 kg/m^3**	**30 kg/m^3**	**20 kg/m^3**	**30 kg/m^3**	**20 kg/m^3**	**30 kg/m^3**
Model Assumptions[1]							
Stocking density	fish/m^3	4.75	7.13	55.06	82.60	27.49	41.24
Growth rate	g/mo	583.00	583.00	37.00	37.00	80.00	80.00
Ex-vessel price	$/kg	5.25	5.25	5.50	5.50	4.75	4.75
Model Description							
Harvest size	kg/fish	5.25	5.25	0.45	0.45	0.97	0.97
Fingerlings used	1,000 pc	85.50	128.34	991.08	1,486.80	494.82	742.32
Fish production	1,000 mt	0.36	0.54	0.36	0.54	0.36	0.54
Feed required	1,000 mt	0.54	0.81	0.54	0.81	0.54	0.81
Model Results							
Net returns	$M	(0.31)	0.34	(0.86)	(0.44)	(0.71)	(0.21)
Payback period	yr	∝	8.54	∝	∝	∝	∝
NPV $M	<0	0.83	<0	<0	<0	<0	
IRR	%	<0	17.04	<0	<0	<0	<0
Investment Decision		Infeasible	**Feasible**	Infeasible	Infeasible	Infeasible	Infeasible

1- stocking size - 10 g/fish; gross feed conversion - 1.5 kg of feed per kg of fish; survival rate - 80%; capital outlay - $2.89 M; grow-out period - 9 mo for cobia and 12 mo for red snapper and red drum.

Table 7. Simulation results of COAPS candidate species ENHANCED MARKET expanded models with 12 cages using two stocking densities.

		COBIA12		SNAP12		DRUM12	
Item	**Unit**	**20 kg/m^3**	**30 kg/m^3**	**20 kg/m^3**	**30 kg/m^3**	**20 kg/m^3**	**30 kg/m^3**
Model Assumptions[1]							
Stocking density	fish/m^3	4.75	7.13	55.06	82.60	27.49	41.24
Growth rate	g/mo	583.00	583.00	37.00	37.00	80.00	80.00
Ex-vessel price	$/kg	5.25	5.25	5.50	5.50	4.75	4.75
Model Description							
Harvest size	kg/fish	5.25	5.25	0.45	0.45	0.97	0.97
Fingerlings used	1,000 pc	171.00	256.68	1,982.16	2,973.60	989.64	1,484.64
Fish production	1,000 mt	0.72	1.08	0.72	1.08	0.72	1.08
Feed required	1,000 mt	1.08	1.62	1.08	1.62	1.08	1.62
Model Results							
Net returns	$M	0.57	1.87	(0.45)	0.39	(0.15)	0.84
Payback period	yr	6.92	2.09	∝	9.94	∝	4.63
NPV	$M	1.70	8.87	<0	0.76	<0	3.24
IRR	%	20.78	59.08	<0	14.97	<0	29.63
Investment Decision		**Feasible**	**Feasible**	Infeasible	**Feasible**	Infeasible	**Feasible**

1- stocking size - 10 g/fish; gross feed conversion - 1.5 kg of feed per kg of fish; survival rate - 80%; capital outlay - $3.85 M; grow-out period - 9 mo for cobia and 12 mo for red snapper and red drum.

Table 8. Simulation results of COAPS candidate species IMPROVED GROWTH base models with 6 cages using two stocking densities.

		COBIA6		SNAP6		DRUM6	
Item	**Unit**	**20 kg/m^3**	**30 kg/m3**	**20 kg/m^3**	**30 kg/m^3**	**20 kg/m^3**	**30 kg/m^3**
Model Assumptions[1]							
Stocking density	fish/m^3	3.80	5.70	44.49	66.74	22.04	33.06
Growth rate	g/mo	729.00	729.00	46.00	46.00	100.00	100.00
Ex-vessel price	$/kg	4.25	4.25	4.50	4.50	3.75	3.75
Model Description							
Harvest size	kg/fish	6.57	6.57	0.56	0.56	1.21	1.21
Fingerlings used	1,000 pc	68.40	102.60	800.05	1,201.20	396.72	595.08
Fish production	1,000 mt	0.36	0.54	0.36	0.54	0.36	0.54
Feed required	1,000 mt	0.54	0.81	0.54	0.81	0.54	0.81
Model Results							
Net returns	$M	(0.64)	(0.16)	(1.04)	(0.72)	(0.97)	(0.61)
Payback period	yr	∝	∝	∝	∝	∝	
NPV	$M	<0	<0	<0	<0	<0	<0
IRR	%	<0	<0	<0	<0	<0	<0
Investment Decision		Infeasible	Infeasible	Infeasible	Infeasible	Infeasible	Infeasible

1- stocking size - 10 g/fish; gross feed conversion - 1.5 kg of feed per kg of fish; survival rate - 80%; capital outlay - $2.89 M; grow-out period - 9 mo for cobia and 12 mo for red snapper and red drum.

species in the Gulf of Mexico are encouraging (Tables 10 and 11). With a simultaneous improvement in fish growth (25%) and price increase ($1/kg), the three candidate species are economically viable at the higher stocking density (30 kg/m^3) and 12 cages in operation (Table 11). With 12 cages in operation, only the culture of cobia is economically viable at the lower stocking density (20 kg/m^3).

Summary

In order to achieve the objectives of this study, several activities were conducted leading to the evaluation of the economic potential of finfish offshore grow-out in the Gulf of Mexico. A hypothetical commercial offshore aquaculture production system (COAPS) was developed based on present information on offshore grow-out technology in the Gulf of Mexico. The projected costs and returns of COAPS were estimated based on recommended management practices, biological knowledge of targeted candidate finfish species, estimated input usage and prices, and established ex-vessel fish prices. Simulation models were developed to evaluate the economic viability of COAPS under different economic and biological scenarios relating to the grow-out of selected species in the Gulf of Mexico.

Simulation results suggested encouraging but limited investment options regarding the culture of cobia, red snapper, and red drum in the Gulf of Mexico, given the biological and economic assumptions of the models. The offshore grow-out of cobia in the Gulf of Mexico is economically feasible when using a 12-cage operation and stocking at the higher density or prices received are $1.00/kg more than reported ex-vessel prices. A simultaneous $1.00/kg increase in prices received, 12-cage growing capacity, and higher stocking density would make offshore grow-out of red snapper and red drum in the Gulf of Mexico economically feasible.

These simulation results are considered preliminary since the models are based on

Table 9. Simulation results of COAPS candidate species IMPROVED GROWTH expanded models with 12 cages using two stocking densities.

		COBIA12		SNAP12		DRUM12	
Item	**Unit**	**20 kg/m^3**	**30 kg/m^3**	**20 kg/m^3**	**30 kg/m^3**	**20 kg/m^3**	**30 kg/m^3**
Model Assumptions[1]							
Stocking density	fish/m^3	3.80	5.70	44.49	66.74	22.04	33.06
Growth rate	g/mo	729.00	729.00	46.00	46.00	100.00	100.00
Ex-vessel price	$/kg	4.25	4.25	4.50	4.50	3.75	3.75
Model Description							
Harvest size	kg/fish	6.57	6.57	0.56	0.56	1.21	1.21
Fingerlings used	1,000 pc	136.80	205.20	1,601.64	2,402.46	793.44	1,190.16
Fish production	1,000 mt	0.72	1.08	0.72	1.08	0.72	1.08
Feed required	1,000 mt	1.08	1.62	1.08	1.62	1.08	1.62
Model Results							
Net returns	$M	(0.97)	0.87	(0.82)	(0.17)	(0.68)	0.05
Payback period	yr	∝	4.49	∝	∝	∝	∝
NPV	$M	<0	3.39	<0	<0	<0	<0
IRR	%	<0	30.45	<0	<0	<0	1.84
Investment Decision		Infeasible	**Feasible**	Infeasible	Infeasible	Infeasible	Infeasible

1- stocking size - 10 g/fish; gross feed conversion - 1.5 kg of feed per kg of fish; survival rate - 80%; capital outlay - $3.85 M; grow-out period - 9 mo for cobia and 12 mo for red snapper and red drum.

Table 10. Simulation results of COAPS candidate species combined ENHANCED MARKET and IMPROVED GROWTH base models with 6 cages using two stocking densities.

		COBIA6		SNAP6		DRUM6	
Item	**Unit**	**20 kg/m^3**	**30 kg/m^3**	**20 kg/m^3**	**30 kg/m^3**	**20 kg/m^3**	**30 kg/m^3**
Model Assumptions[1]							
Stocking density	fish/m^3	3.80	5.70	44.49	66.74	22.04	33.06
Growth rate	g/mo	729.00	729.00	46.00	46.00	100.00	100.00
Ex-vessel price	$/kg	5.25	5.25	5.50	5.50	4.75	4.75
Model Description							
Harvest size	kg/fish	6.57	6.57	0.56	0.56	1.21	1.21
Fingerlings used	1,000 pc	68.40	102.60	800.82	1,201.32	396.72	595.08
Fish production	1,000 mt	0.36	0.54	0.36	0.54	0.36	0.54
Feed required	1,000 mt	0.54	0.81	0.54	0.81	0.54	0.81
Model Results							
Net returns	$M	(0.29)	0.36	(0.70)	(0.20)	(0.63)	(0.09)
Payback period	yr	∝	8.09	∝	∝	∝	∝
NPV	$M	<0 0.93	<0	<0	<0	<0	
IRR	%	<0	17.90	<0	<0	<0	<0
Investment Decision		Infeasible	**Feasible**	Infeasible	Infeasible	Infeasible	Infeasible

1- stocking size - 10 g/fish; gross feed conversion - 1.5 kg of feed per kg of fish; survival rate - 80%; capital outlay - $2.89 M; grow-out period - 9 mo for cobia and 12 mo for red snapper and red drum.

hypothetical or "best guess" scenarios. Further research is required to discover new markets for selected species, verifying biological assumptions of the models, and solving logistical problems involved in the construction and operation of an offshore production system in the Gulf of Mexico. To achieve sustainability, the costs of monitoring and maintaining a suitable environment surrounding the offshore operation should be considered in later evaluations.

ECONOMIC IMPACT OF OFFSHORE AQUACULTURE

Methods

The potential economic impact of operating a single COAPS, consisting of a single ASV and 12 offshore aquaculture cages, as previously described, was estimated by using IMPLAN Professional 2.0 Software and the 2000 Gulf of Mexico States IMPLAN data files, including Florida, Alabama, Mississippi, Louisiana and Texas. These impact planning software and data files facilitated the estimation of economic impacts with the use of the most appropriate multipliers (MIG 1999).

Two series of economic impact estimates were prepared for the offshore aquaculture industry. The first series of estimates included those associated with the initial investment expenditures that would be incurred during the establishment or construction year. The second series of estimates covered those annual expenditures that would be incurred in operating the COAPS. Offshore aquaculture production facilities would also enhance both commercial and recreational fishing opportunities in the nearby waters by serving as a fish aggregating device (Costa-Pierce and Bridger 2002). Additional production of the candidate species would also increase processing and distribution activities in both existing and new processing and distribution plants.

The COAPS sector was represented by the "Miscellaneous Livestock " IMPLAN sector 9 which corresponded to the 1987 Bureau of Economic Analysis (BEA) Standard Industrial Classification (SIC) codes 0271 and 0272 (MIG 1999). The commercial seafood processing sector involves plants engaged in primary wholesale and processing activities. IMPLAN sector "Prepared Fresh or Frozen Fish or Seafood, 98" corresponded to the 1987 BEA-SIC code 2092 (MIG 1999). Commercial harvesting is represented by IMPLAN sector 25, which corresponded to the 1987 BEA-SIC code 0910 (MIG 1999). The ex-vessel values of the Gulf of Mexico commercial fishing sector were retrieved from the NMFS (2004) website.

Extrapolating a potential offshore aquaculture industry from these hypothetical COAPS models is difficult. Several key economic and marketing issues need to be addressed when projecting an industry-wide economic impact of offshore aquaculture from multiple COAPS, each consisting of 12-cages. There is no published inventory of suitable offshore areas for offshore aquaculture operations that lack conflicts with present and future users of these marine resources. Reliable information to predict the reaction of the domestic market to further product supplies of the cultured species arising from offshore aquaculture and imports from foreign producers are nonexistent. Public perceptions, legal and political mind-sets, and environmental constraints associated with offshore aquaculture, required to make the investment climate more favorable, have also not been addressed. Finally, present regulations affecting the harvesting, production and marketing of the candidate species in both state and fed-

Table 11. Simulation results of COAPS candidate species combined ENHANCED MARKET and IMPROVED GROWTH expanded models with 12 cages using two stocking densities.

		COBIA12		SNAP12		DRUM12	
Item	**Unit**	**20 kg/m^3**	**30 kg/m^3**	**20 kg/m^3**	**30 kg/m^3**	**20 kg/m^3**	**30 kg/m^3**
Model Assumptions[1]							
Stocking density	fish/m^3	3.80	5.70	44.49	66.74	22.04	33.06
Growth rate	g/mo	729.00	729.00	46.00	46.00	100.00	100.00
Ex-vessel price	$/kg	5.25	5.25	5.50	5.50	4.75	4.75
Model Description							
Harvest size	kg/fish	6.57	6.57	0.56	0.56	1.21	1.21
Fingerlings used	1,000 pc	136.80	205.20	1,601.64	2,402.64	793.44	1,190.16
Fish production	1,000 mt	0.72	1.08	0.72	1.08	0.72	1.08
Feed required	1,000 mt	1.08	1.62	1.08	1.62	1.08	1.62
Model Results							
Net returns	$M	0.59	1.91	(0.13)	0.87	0.02	1.09
Payback period	yr	6.59	2.05	∝	4.52	250.24	3.60
NPV	$M	1.86	9.09	<0	3.36	<0	4.58
IRR	%	21.68	60.14	<0	30.27	0.33	36.93
Investment Decision		**Feasible**	**Feasible**	Infeasible	**Feasible**	Infeasible	**Feasible**

1- stocking size - 10 g/fish; gross feed conversion - 1.5 kg of feed per kg of fish; survival rate - 80%; capital outlay - $3.85 M; grow-out period - 9 mo for cobia and 12 mo for red snapper and red drum.

eral waters represent potential constraints every grower, lender or investor will have to consider prior to entrance into this novel aquaculture sector.

Results and Discussion

Impact of Initial Investment in a Single COAPS

The initial investment expenditures that would be incurred in establishing a single COAPS with 12 cages during its establishment year would generate additional output of economic goods and services valued at U.S. $6.84 million. Associated with this added economic activity would be an increase in the derived demand for 197 workers. The expected increase in labor income, which consists of employee compensation and proprietor's income, would reach U.S. $2.17 million. Indirect business tax collections are estimated at $210,870 (Table 12). Federal income tax collections would include $231,000 from personal income taxation and $59,000 from corporate income taxation.

Annual Impact of Operating a Single COAPS

A single COAPS with 12 cages stocked with either of the candidate species would require different levels of input usage, primarily fingerlings and feed (Table 11). Annual fish production would be 1.08 x 10^3 metric tons for all three species. Differences in ex-vessel prices would generate varying levels of annual fish sales: cobia—$5.67 x 10^6, red snapper—$5.94 x 10^6, and red drum—$5.13 x 10^6.

The economic impact to the Gulf of Mexico region, using the annual fish sales expected from the single COAPS with 12 cages, was measured using four indicators: output of goods and services, employment, labor income, and indirect business taxes (Table 13). Using the same 2000 Gulf of Mexico IMPLAN model, additional output produced would range from $9.1 x 10^6 to $10.2 x 10^6. The number of jobs created would be between 262–289 positions. The single COAPS would generate additional pro-

Table 12. Summary of economic impact of initial investment expenditures on a single COAPS using 12 cages incurred during the establishment year.

Item	Output ($ x 10^6)	Employment (jobs)	Labor Income ($ x 10^6)	Indirect Business Taxes $ x 10^3)
Direct	3.85	156	1.17	46.33
Indirect	1.59	24	0.49	74.67
Induced	1.40	17	0.51	89.86
Total	6.84	197	2.17	210.86

prietor income and employee compensation ranging from $2.9 x 10^6 to $3.2 x 10^6. Annual indirect business taxes associated with the added output produced by a single COAPS would amount to at least $281,000. This tax collection does not include personal income taxation that could be collected from employment and ownership of the COAPS. Federal and state personal income tax collections from households would amount to $340,000 and $11,000, respectively. Tax collections from corporate profits would reach $87,000 and $4,000 for federal and state taxing authorities, respectively.

Impact of Current Commercial Fish Harvesting

Commercial harvesting of the candidate species is limited by state and federal regulations. Recent domestic commercial landings valued at ex-vessel prices exceeded U.S. $10 million. Using the same 2000 Gulf of Mexico IMPLAN model, the commercial landings valued at U.S. $12.4 million could have created an economic impact in the region amounting to U.S. $20.1 million output of goods and services if it were all landed in the Gulf of Mexico. A total of 628 jobs could have been created and a combined income of workers and proprietors could reach U.S. $10.3 million. Business establishments would also remit indirect business taxes amounting to $856.7 x 10^3 (Table 14).

Impact of Current Commercial Foodfish Processing

The 64 Gulf of Mexico processing plants engaged in the primary processing and wholesaling of foodfish handled a total plant-gate value of foodfish products amounting to U.S. $52.7 million in 2000 (NMFS 2004). By using the same 2000 Gulf of Mexico IMPLAN model, total economic impact of commercial foodfish processing reached U.S. $80.8 million. This sector also provided 769 jobs and generated U.S. $17.6 million in labor income for the region. Indirect business taxes collected from this sector amounted to U.S. $1.3 million (Table 15).

Sectoral Economic Linkages

The direct effects created by establishing and operating a single COAPS with 12 cages would generate indirect and induced effects. Indirect effects consist of the inter-industry effects of the input-output analysis. Induced effects consist of the impact of household expenditures in input-output analysis (MIG

Table 13. Summary of annual economic impact of a single COAPS using 12 cages stocked with candidate species under enhanced market and improved growth conditions.

	Output ($ x 10^6)			Employment (jobs)			Labor Income ($ x 10^6)			Indirect Business Taxes ($ x 10^3)		
Item	COBIA	SNAPPER	DRUM	COBIA	SNAPPER	DRUM	COBIA	SNAPPER	DRUM	COBIA	SNAPPER	DRUM
Direct	5.7	5.7	5.1	229	232	208	1.7	1.7	1.6	68.1	69.0	61.7
Indirect	2.3	2.4	2.1	35	36	32	0.7	0.7	0.6	109.8	111.2	99.5
Induced	2.1	2.1	1.9	25	25	22	0.7	0.8	0.7	132.2	133.8	119.7
Total	10.1	10.2	9.1	289	293	262	3.1	3.2	2.9	310.1	314.0	280.9

Table 14. Summary of annual economic impact of combined commercial fish harvesting of cobia, red snapper, and red drum in the Gulf of Mexico, 2000.

Item	Output ($ x 10^6)	Employment (jobs)	Labor Income ($ x 10^6)	Indirect Business Taxes ($ x 10^3)
Direct	12.4	586	7.6	389.9
Indirect	0.9	8	0.3	33.6
Induced	6.7	34	2.5	433.2
Total	19.0	628	10.4	856.7

Table 15. Summary of annual economic impact of commercial foodfish processing in the Gulf of Mexico, 2000.

Item	Output ($ x 10^6)	Employment (jobs)	Labor Income ($ x 10^6)	Indirect Business Taxes ($ x 10^3)
Direct	52.7	338	7.3	318.1
Indirect	17.0	297	6.3	1,009.4
Induced	11.1	133	4.0	0.7
Total	80.8	768	17.6	1,328.2

1999). The sum of the direct, indirect, and induced effects is equal to the total economic impact measured in terms of output ($), jobs, labor income ($), and tax collections ($). The indirect or inter-industry linkages would mostly occur among the agriculture (27%), manufacturing (23%), trade (14%), and transportation, communication and public utilities (TCPU = 14%) sectors (Fig. 1). Additional indirect linkages could be expected from the services (8%), and finance, insurance and real estate (FIRE = 7%) sectors. The induced effects associated with increased household expenditures would be mostly observed among the services (30%), trade (24%) and FIRE (23%) sectors (Fig. 2). The manufacturing and TCPU sectors would share some of the induced effects (9%) generated by added household spending.

Fig. 1. Percent distribution of indirect annual economic impact of a single COAPS using 12 cages stocked with candidate species under enhanced market and improved growth conditions.

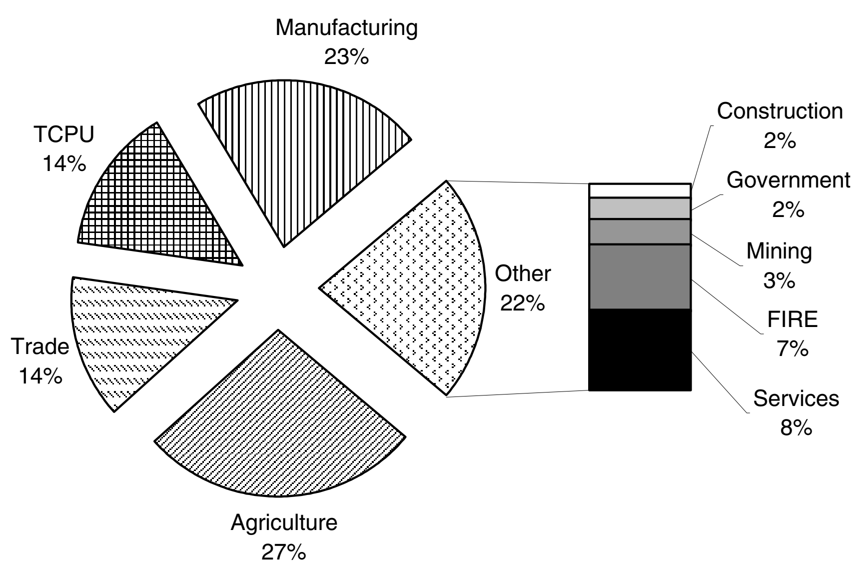
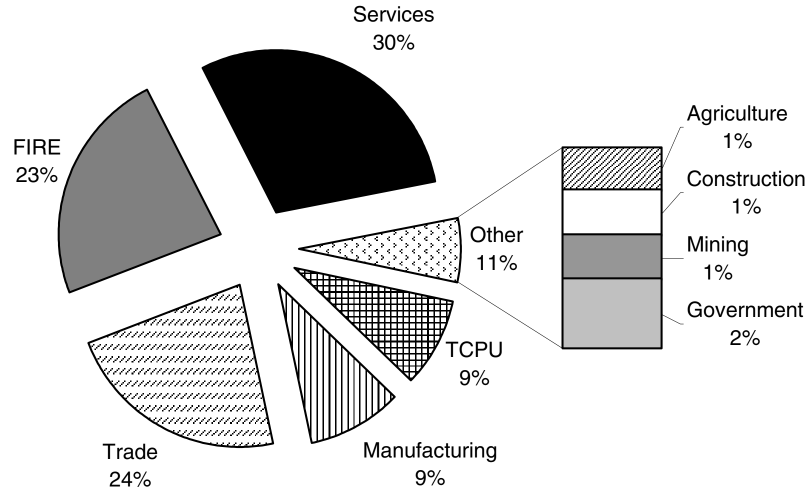


Fig. 2. Percent distribution of induced annual economic impact of a single COAPS using 12 cages stocked with candidate species under enhanced market and improved growth conditions.



ECONOMIC CONSIDERATIONS RELATED TO FINGERLING TRANSPORT

As alluded to earlier, the logistical problem of transporting feed and market-size fish has not been adequately examined. We have compared the economic inputs required for different methods to transport fingerlings to a distant offshore aquaculture site. These methods include: a) hauling fingerlings in live-haul trucks from the hatchery/nursery, transferring these fish to barge tanks thereby keeping the fingerlings safely on deck during the offshore transport, and a final transfer to the awaiting cage (LHT); b) craning fingerling tanks from a flatbed truck to a barge deck thereby eliminating one fingerling handling step while maintaining safe transport offshore (FBT); and, c) transporting fingerlings dockside and transferring them to individual offshore cages and towing fingerlings in the cage to the distant offshore aquaculture site thereby eliminating the need to transfer fingerlings to the cage offshore.

Both LHT and FBT are estimated to require a total of 12 hours for each transport trip. Cage towing is expected to be much slower than transporting fish offshore in tanks placed on the vessel deck. In total, cage towing transport is estimated to require 22 hours per trip (Table 16). Initial investment on equipment required to transport fingerlings would reach up to $11,844 per system (Table 17). There are no allocations for the purchase of livehaul trucks or flatbed trucks since they are assumed to be available for rent or lease on a per trip or mileage basis. Similar assumptions were made for cranes at the dock and barge. Due to these assumptions, the annual costs of fingerling transport consisted mostly of operating expenses (Table 18). Annual transport costs would range from $101,500 for the FBT and towing option to $116,075 for the LHT and barge transport option.

The method that results in the least fingerling mortality during transport would be the ultimate choice. Both trucking options that involve transporting fingerlings offshore by cage towing require much greater duration of

Table 16. Methods of transporting fingerlings from nursery ponds to offshore cages and anticipated hours required to complete each phase of transport.

Method	Hours
Using Livehaul Truck (LHT) and Barge	
Load fingerlings in LHT compartments at the nursery	2.00
Haul fingerlings in LHT to dock	2.00
Unload fingerlings to livehaul tanks on board barge	2.00
Transport livehaul tanks on board barge to offshore cages	4.00
Unload fingerlings from livehaul tanks to offshore cages	2.00
Total	12.00
Using Flatbed Truck (FBT) and Barge	
Load fingerlings in livehaul tanks on board FBT at the nursery	2.00
Haul fingerlings in livehaul tanks on board FBT to dock	2.00
Crane LH tanks from FBT to barge	2.00
Transport livehaul tanks on board barge to offshore cages	4.00
Unload fingerlings from livehaul tanks to offshore cages	2.00
Total	12.00
Using LHT or FBT and Cage Towing	
Load fingerlings to LHT or FBT at the nursery	2.00
Haul fingerlings to LHT or FBT to dock	2.00
Unload fingerlings from LHT or FBT to cages at dock	2.00
Tow cages to offshore farm site	16.00
Total	22.00

time thereby increasing the risk involved with the operation. Cage towing operations also would be limited to defined shipping channels close to shore along much of the Gulf of Mexico. This further increases operational risks through heightened potential for interactions with other marine traffic. Finally, cages towed to the offshore site must be immediately connected to the mooring system. However, cage connection would be jeopardized if surface conditions are not optimal. This risk would only be mitigated if cages are maintained at the offshore site and the fingerlings transported to moored cages. Both the LHT and FBT options are identical when comparing duration for transport and capital equipment investment and quite comparable with regards to associated operational costs. However, use of the LHT option requires additional handling of individual fingerlings (required to transfer fingerlings from the pond to LHT and from LHT to barge tanks) compared with FBT (required only to transfer fingerlings from the pond to livehaul tanks on the FBT but having each livehaul tank transferred to the barge with a crane). One less handling step involved with the FBT option will greatly reduce operational stress to the fingerlings and therefore the most optimal means to transport fingerlings to offshore aquaculture cages.

CONCLUSIONS

The culture of cobia, red snapper and red drum using commercial offshore cages and the proposed aquaculture support vessel in the Gulf of Mexico has limited economic potential given the present biological information, cost structure of the offshore production technology, and established ex-vessel market prices. Only cobia can be considered a viable candidate species for offshore culture using either six or 12 cages. The economic and biological constraints to offshore aquaculture of these species in the Gulf of Mexico, however, could be adequately managed to promote the growth of this emerging industry. Economic feasibility of offshore grow-out of the selected species can be enhanced by a combination of revenue-enhancing and cost-reducing measures, including improvement in fish growth and market development. With improved growth and enhancement of market prices, the offshore culture of red snapper and red drum

Table 17. Capital equipment investment requirements for fingerling transport.

Item	Description	LHT and Barge ($)	FBT and Barge ($)	LHT and Towing ($)	FBT and Towing ($)
Live transport tanks	268 gal	9,444	9,444	0	9,444
Pure oxygen tanks	Units	100	100	0	100
Regulators, hoses and airstones	Units	100	100	0	100
Oxygen meter	W/4m cable	800	800	800	800
Water pump	10 hp	1,000	1,000	1,000	1,000
Corrugated water hoses	100 ft each	400	400	400	400
Total		11,844	11,844	2,200	11,844
Assumptions					
Total fingerlings stocked	#/crop	1,200,000	1,200,000	1,200,000	1,200,000
Fingerlings transported	#/trip	100,000	100,000	100,000	100,000
Average fingerling size	g/fish	10	10	10	10
Total fingerling weight	lb/trip	2,205	2,205	2,205	2,205
Livehaul tank stocking rate	lb/gal	1	1	1	1
Number of transport trips	trips/crop	12	12	12	12
Number of crops per year	crops/yr	1	1	1	1

in 12 offshore cages could be considered economically viable.

The annual economic impact to the Gulf of Mexico region of a single offshore aquaculture production system consisting of 12 cages would consist of additional economic output ranging from $\$9.1 \times 10^6$ to $\$10.2 \times 10^6$. In comparison, current commercial harvesting of the three candidate species in the Gulf of Mexico, which are limited by state and federal regulations, created a total economic impact in the region amounting to $\$20.1 \times 10^6$. The subsequent primary processing and wholesaling of all food fish species in the Gulf of Mexico created a total economic impact reaching $\$80.8 \times 10^6$.

Table 18. Total costs associated with fingerling transport.

Item	LHT and Barge ($)	FBT and Barge ($)	LHT and Towing ($)	FBT and Towing ($)
Variable Costs				
Crane services	0	12,000	0	0
Trucking services	28,800	14,400	28,800	14,400
Barge services	72,000	72,000	72,000	72,000
Pure oxygen	1,200	2,400	0	1,200
Labor	1,440	1,440	2,640	2,640
Fuel for pumps	101	50	50	50
Repair and maintenance	538	538	365	538
Interest on operating capital	10,408	10,283	10,386	9,083
Total variable costs	114,487	113,111	114,241	99,911
Fixed Costs				
Depreciation	996	996	340	996
Interest on investment	592	592	110	592
Total fixed costs	1,588	1,588	450	1,588
Total costs	116,075	114,700	114,691	101,500

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