An Economic Evaluation of Commercial Paddlefish (*Polyodon spathula*) Production

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Abstract. Potential changes in the tobacco program have prompted research of aquaculture crops in Kentucky. Using a dynamic, programming model, this paper evaluates two methods for producing pond-raised paddlefish to assess if either method is economically viable in Kentucky. Results indicate that a polyculture system with catfish is profitable.

Key Words: Aquaculture, dynamic programming, paddlefish, production economics.

In an era of uncertainty in the tobacco program, Kentucky farmers, particularly smaller farmers, need a profitable alternative to growing tobacco. In addition to expansion of the wood products industry, development of various horticultural crops, and other ideas, aquaculture products are being explored as possible revenue generating options. In particular, the state has invested a significant amount of money in the research and development of fresh water shrimp, bait fish, and catfish products. In most products, Kentucky is at an absolute and (or) technical disadvantage relative to other southern states in aquaculture. This has lead state and university leaders to consider development of freshwater species that thrive in Kentucky's cooler climate.

Paddlefish (*Polyodon spathula*) occur naturally in Kentucky's rivers. Different groups such as fish farmers, commercial fishermen, and researchers have expressed an interest in the development of a commercial paddlefish industry in Kentucky. Industry promoters are most interested in the "value added" aspects of the processed products. The products from paddlefish that are of most interest include the meat and roe. The meat filets can be smoked (or processed in other ways) or they can be sold directly. Unprocessed filets are primarily consumed as "boneless" catfish. The greatest added value is derived from the conversion of paddlefish roe into caviar. Furthermore, the harvesting of paddlefish roe has beneficial environmental implications. Specifically, many of the European fish stocks commonly associated with caviar brands have been severely depleted.

Currently, the commercial industry relies on the harvest of paddlefish from the Ohio River. Unfortunately, the stock of paddlefish in the Ohio River is not sufficient to support expansion of a commercial industry in Kentucky. Furthermore, recent river harvests have not produced the large mature females in sufficient quantities to supply even Kentucky's fledgling caviar industry. Further development of the industry requires the use of flat water systems (ponds, lakes, and reservoirs).

Unfortunately, currently there is agency opposition within state level agencies to raising paddlefish for commercial harvest in public ponds and lakes. For this reason attention has focused on development of private ponds or "fish farms." However, the feasibility of using ponds to develop a viable commercial paddlefish industry remains a debatable issue. The feasibility of raising paddlefish in ponds will depend on the market price for paddlefish and their value-added products, plus the costs of operating a paddlefish farm. The purpose of this paper is to evaluate two methods for producing pond-raised paddlefish to assess if either method is economically viable in Kentucky.

Empirical Model of Pond Raised Paddlefish

Shaefer was the first to jointly model the natural, dynamic growth and harvesting processes of a fishery. Since Shaefer, numerous examples of dynamic programs that apply to fisheries have been developed. For example, Larkin and Sylvia developed a seasonal bioeconomic programming model to describe the vertically integrated Pacific Whiting (Merluccius productus) industry. Using the General Algebraic Modeling System (GAMS) nonlinear solver, they use their model to determine an optimal management plan. This article is particularly useful for demonstrating how a model can be structured to account for changes in stock through time. Similarly, Onal et. al. provide examples of models that demonstrate how to maximize social welfare subject to biological and economic aspects.

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Following Larkin and Sylvia, this investigation utilizes a mixed integer programming model to calculate the present value of a stream of net benefits derived from two different production processes (paddlefish as a monoculture and paddlefish and catfish in a polyculture) and 7 different production schedules over a 20 year planning horizon (Equation 1).

(1)

$$\underset{\{H_{s,t}\ Pond_{s,t}\}}{Max}\ NPV(\pi) = \sum_{s=1}^{s}\sum_{t=1}^{t}\left[Rev(H_{s,t}) - Cost(Pond_{s,t})\right]\left(\frac{1}{(1+r)^{t}}\right)$$

$$H_{s,t} \le \{Fish\ Per\ Pond\} * Pond_{s} \quad \because t$$

$$H_{s,t} \ge 0 \quad \because s\ and\ t$$

$$Pond_{s,t} = 0,1,\ldots,n \quad \because s\ and\ t$$

$$\sum_{s=1}^{s} Pond_{s,t} \le \frac{Total\ Acres}{Acres\ per\ Pond} \quad \because t$$

In Equation 1, a farm manager chooses the number of ponds to construct ($Pond_{s,t}$) and the number of fish in each pond to harvest ($H_{s,t}$) that maximizes the net present value (NPV) of profit (π) through time (t = 20) and across 7 different production schedules (s = 7). Profits are constrained by the size of the pond, which determines the total number of fish that can be caught, and by the size (in acres) of the fish farm.

Profit (π), or net return, is the difference between revenues earned ($Rev(H_{s,t})$) per fish harvested and production and fixed operating costs ($Cost(Pond_{s,t})$) on a per pond basis. Revenues can be earned from three sources; catfish meat, paddlefish meat, and paddlefish roe (Equation 2). With respect to paddlefish filets, this investigation is concerned with production of the raw product, hence prices reflect the raw product and not value added processing. When polyculture production is assumed, catfish (cf) are sold on a per fish basis where price (P_{cf}) reflects the value of the raw product. The price of roe (P_r) reflects the value of roe as caviar.

(2)

$$Rev(H_{s,t}) = \left[(P_m * dpr * wt_{s,t}) + (P_r * rwt * pfemale)\right] * survive_{s,t} * H_{s,t} + (P_{cf} * cf * Pond_{s,t})$$

The remaining parameters in Equation 2 include the dressing percentage of paddlefish (dpr), the weight of the paddlefish ($wt_{s,t}$), the weight of harvested roe per paddlefish (rwt), the percentage of the population that is female (is capable of producing roe; pfemale), the number of fish that survive to harvest ($survive_{s,t}$), and the number of catfish raised per pond (cf). Note that the parameters wt and survive depend on the age of the fish which is a function of the production schedule used (production schedules are described later). Specifically, the older the paddlefish the larger the harvested fish, but there are fewer that survive in each successive year due to natural mortality and other causes. Finally, the dressing percentage of paddlefish (dpr) is the percent of meat in filets that can be cut from the paddlefish.

Production and fixed operating costs are defined in Equation 3. Here P_f is the price of 6 inch paddlefish smolts, $Feed_{s,t}$ is the cost of feeding paddlefish if raised as a monoculture, opp cost is the operational cost of a pond, and cap cost the capital cost of a pond. Note that opp cost does depend upon the production system used. Specifically, in a monoculture, costs associated with catfish are excluded, but it becomes necessary to feed the paddlefish. In this case, paddlefish feed costs are separated from operational costs because the amount fed depends upon the age of the paddlefish which is a function of the chosen production schedule. Equation 4 defines feed costs when paddlefish are grown as a monoculture. In Equation 4 P_{Feed} is the price of feed ($/ton) and C_{Feed} is the rate at which feed is converted into body weight. Note that the defined parameters of Equation 4 are divided by 2000 in order to convert tons to pounds. In the case of a polyculture, the feed fed to catfish and the waste produced by the catfish provides the nutrients needed to generate the zooplankton needed to feed the paddlefish. Here, $Feed_{s,t}$ is zero and opp cost includes the cost of raising catfish on an annual schedule.

(3)

$$Cost(Pond_{s,t}) = P_f * H_{s,t} + (Feed_{s,t} + Opp\cos t + Cap\cos t) * Pond_{s,t}$$

(4)

$$Feed_{s,t} = \left(\frac{P_{Feed} * C_{Feed} * Wt_{s,t} * Survive_{s,t}}{2,000} \right) H_{s,t}$$

Again, it is assumed that ponds have a useful life of 20 years (have a planning horizon of 20 years) and that fish can be produced over this 20 year period by following one or more of 7 production schedules. To produce roe, a female paddlefish must be approximately 7 years of age or around 40 pounds in weight. Females harvested at younger ages are suitable for meat production, but will earn no income from roe. Hence, for roe (and meat production since extraction of roe is lethal to the paddlefish) the producer must incur 7 years of cost before realizing a return on the investment. The production schedules utilized here capture the temporal relationships between costs and returns. Specifically, the model chooses the number of ponds which grow paddlefish on 1, 2, 3, 4, 5, 6, and (or) 7 year production schedules. The 7 year schedule provides returns for both meat and roe. At no time during the 20 year planning period is a pond left without a fish. For example, on the 6 year schedule, the pond goes through 3 complete 6-year cycles with the fish raised in the 4th cycle harvested in the second year. GAMS coding for the objection function, relevant constraints, and the 7 production cycles is provided in Appendix 1.

Data

Data concerning the cultural practices needed to raise paddlefish in ponds was provided by Dr. Steve Mims of Kentucky State University. This section describes the data needed to parameterize the model used in this investigation. A production cycle begins with the release of smolts into a pond. Each paddlefish smolt costs \$0.10 per fish (P_f, Equation 3). Again, paddlefish are filter feeders, meaning they consume nutrients by filtering microorganisms from the water. On average, paddlefish gain 0.5 pounds a month, or six pound a year (wt, Equation 2). If grown as a monoculture, smolts (and older paddlefish) have to be fed. The feeding of smolts requires that the pond be seeded with fertilizer. The fertilizer aids the growth of the microorganisms upon which the paddlefish feeds. These fertilizers cost \$1,100 per acre of pond.

The largest costs incurred, involve the construction and daily operational costs of the ponds. According to Mims, the pond needed to produce paddlefish is similar in design to catfish ponds. Annual production costs and ownership costs are based on the data provided by Stone et al. for small scale catfish production, utilizing six two-acre ponds (Table 1). This data suggests that each 12 acre pond unit costs \$14,360 annually to operate and maintain (opp cost, Equation 3) with an additional \$15,042 being paid annually in ownership (principal and interest) costs (cap cost, Equation 3). Constant economies of scale are assumed, hence each addition 12 acre pond unit brought into production costs an additional \$29,402 per pond per year. However, the model chooses the number of ponds to construct in the first year and maintains that number of ponds throughout the remaining 19 years.

The costs described above assume monoculture production of paddlefish. In the case of polyculture production with catfish, added costs arise from the stocking of fingerlings and the need to feed the catfish. These costs add \$20,385 to oppcost (Table 1) for a total of \$34,745 per pond annually. Ownership costs are not impacted by polyculture production. Recall also that feed costs for the paddlefish ($Feed_{s,t}$) no longer need to be paid in this case.

Given that ponds are constructed in 12 acre units, acreage available for construction (the size of the fish farm) is need to determine the total number of ponds that can be built and the number of fish to be produced. A twelve-acre pond unit needs approximately 3 acres of surrounding service acreage to allow for outbuilding and pond access (15 acres total; Acres per Pond, Equation 1). Farm size is assumed to be 80 acres in this study (Total Acres, Equation 1).

The carrying capacity of a pond unit is 5,000 pounds of catfish and (or) 500 pounds of paddlefish per acre. Given that paddlefish grow at a rate of 6 pounds per year, each pond can grow from 150 paddlefish, if on a 7 year schedule, to 1,000 paddlefish if grown like catfish on a single year schedule (Fish Per Pond, Equation 1). Unfortunately, pond mortality must be considered. Currently, information concerning the mortality of pond raised paddlefish does not exist. This study assumes that mortality increases 1 percent per year for fish 1 to 7 years of age. Hence, if on a 7 year (roe) schedule, of the 139 paddlefish released as smolts, only 105 would survive to harvest. In Equation 2, the parameter $survive_{x,t}$ is equal to 1 less the rate of mortality as described above.

The remaining parameters include dpr, rwt, pfemale, P_{Feed}, C_{Feed}, and r. P_m and P_r are also parameters, but their values are reported in Results. For every pound of paddlefish produced, 0.25 pounds can be sold as filet (dpr in Equation 2). Half of the paddlefish population is assumed to be female (pfemale in Equation 2) and a mature (7 year old) paddlefish produces 5 pounds of roe (rwt, Equation 2). Research by Mims has lead to a process by which all hatchery produced paddlefish are female, but this process is not considered here. When grown alone, paddlefish require a special feed that costs \$1,100 per ton (P_{Feed}; Equation 4). According to personal correspondence with Dr. Steve Mims (2000), paddlefish are able to convert feed into flesh at a rate of 2 pounds of feed for every pound of paddlefish (C_{Feed}; Equation 4). In this investigation, revenues and costs are discounted at 4 percent (r, Equation 2).

Finally, each catfish receives a wholesale price of $0.75 per pound ($P_{cf}$, Equation 2; personal correspondence, Dr. Tim Woods, 2000). Given that each pond can produce 60,000 pounds of catfish annually (5,000 pound capacity per acre times 12 acres), catfish can earn $45,000 per pond. Again, the added cost of growing catfish is $20,385 (oppcost; Table 1), hence growing catfish with paddlefish adds $24,615 in revenue per 12 acre pond. However, the costs reported in Table 1 also indicate that if catfish are grown as a monoculture, such an enterprise would lose $5,787 per pond per year. Given the costs reported in Table 1, the breakeven price of catfish is 83 cents per pound.

Results

Returns to paddlefish production are determined for mono and polyculture paddlefish production given price estimates by Mims for filets (P_m) and roe (P_r). Specifically, the current (1998) wholesale price for filets is anticipated to be $6 per pound (sold as "boneless catfish") and the price of roe is $42 per pound. Because the estimates provided by Mims are not derived from marketing studies or actual cash prices, the sensitivity of model results to changes in these prices is evaluated using "high" and "low" prices. For either product, the low price is one half of the price reported by Mims ($3 for meat and $21 for roe). Similarly, the high price is twice the reported price ($12 for meat and $84 for roe). Whether these high prices could be attained is not known. In this way, returns for the base prices and 4 categories of price expectations (high meat and high roe, high meat and low roe, low meat and high roe, and low meat and low roe) are reported for each of the 7 production schedules (Table 2). Values in the table are the net present value of profit (revenues less cost) over the 20 year life of the ponds discounted at 4 percent.

Using the average prices reported by Mims, the model was allowed to choose the optimal production schedule, the number of ponds produced, and the number of fish harvested for both mono and polyculture production systems. For monoculture production, none of the 7 production systems was profitable. For polyculture production the model chose to harvest annually (production schedule1) earning $273,369 (in current value) over the 20 year production cycle. In this case, the maximum number of ponds (5) were brought into production.

To evaluate the remaining scenarios relative to the optimum solution, the model was restricted to produce 5 ponds for each of the 7 production schedules. In this way the results reported in table 2 were generated. The results of Table 2 clearly show that monoculture pond production of paddlefish is not economically feasible in Kentucky. Regardless of the assumed price for meat or roe negative returns were earned. Across the price scenarios, smallest losses were earned when producing paddlefish for roe (schedule 7).

Again for pond raised paddlefish, profits are earned only when paddlefish are raised with catfish. Table 2 shows that at current prices an annual harvest schedule maximizes the net present value of profits. High meat prices generate profits for ponds on 1, 2, or 3 year schedules, but with successively lower profits for each year that the paddlefish are allowed to grow. The combination of high meat prices with high roe prices in the only price scenario where roe production (raising paddlefish for 7 years) is profitable. Note, however, that at low meat prices, the pond polyculture of paddlefish, like monoculture production, is not profitable.

Conclusions

In an era of uncertainty in the tobacco program, Kentucky farmers, particularly smaller farmers, need a profitable alternatives to growing tobacco. In addition to expansion of the wood products industry, development of various horticultural crops, and other ideas, aquaculture products are being explored as possible revenue generating options. In particular, the state has invested a significant amount of money in the research and development of fresh water shrimp, bait fish, and catfish products. In most products, Kentucky is at an absolute and (or) technical disadvantage relative to other southern states in aquaculture. This has lead state and university leaders to consider development of freshwater species that thrive in Kentucky's cooler climate.

The purpose of this paper is to evaluate two methods for producing pond-raised paddlefish to assess if either method is economically viable in Kentucky.

Different groups such as fish farmers, commercial fishermen and researchers have expressed an interest in the development of a commercial paddlefish industry in Kentucky. Industry promoters are most interested in the "value added" aspects of the processed products. The products from paddlefish that are of most interest include the meat and roe. The meat filets can be smoked or processed in other ways or they can be sold directly. Unprocessed filets are primarily consumed as "boneless" catfish. The greatest added value is derived from the conversion of paddlefish roe into caviar.

The results of this investigation indicate that pond raised paddlefish (as a single species or monoculture) are not economically viable in Kentucky given the assumed price ranges for meat and roe. While perhaps, discouraging, this result was not unanticipated. Specifically, paddlefish are relatively large which translates into a lower carrying capacity compared to most other commercial , pond raised, freshwater fish species. More importantly, caviar production requires that the fish be grown 7 years. In this case costs are incurred every year with revenues earned only once in every 7 years.

Results concerning the economic viability of joint (polyculture) production of pond raised paddlefish and catfish are more promising. Specifically, at anticipated and high meat prices, polyculture production is profitable if paddlefish and catfish are harvested annually. The harvest of paddlefish every second or third year is also profitable, but less so than annual harvest and only at high meat prices. At low meat prices, polyculture production is not profitable. This result emphasizes that a pond based paddlefish industry would face a high degree of price risk.

While it is clearly demonstrated that monoculture paddlefish production is not profitable in Kentucky, this study also reveals that monoculture catfish production is only marginally profitable, if profitable at all. At the assumed current market price (which is the actual cash price in Kentucky), monoculture of catfish results in an income loss. Based on the production and ownership costs assumed in this study, the breakeven price of catfish is 83 cents per pound. This is a relatively high price to attain in a state that is at a technical disadvantage in catfish production.

While the focus of this paper was paddlefish production, the results of this study illustrate that successful commercial production of either pond raised paddlefish or catfish in Kentucky requires the joint production of both species. More too the point, the survival of a commercial catfish industry in Kentucky (the industry with the most momentum with respect to political and financial support) may require the successful establishment and promotion of a commercial paddlefish industry. One industry is less likely to survive without the other.

Caviar (roe) production was profitable in only one scenario; high meat and roe prices. While again, perhaps discouraging, the high roe price utilized in this study is well within the range of possible prices. Great uncertainty surrounds the price of roe because of the current state of caviar producing fish stocks in Russia and other Eastern European Countries. Many of these stocks have been severely depleted. While not, perhaps, a perfect substitute, anticipated restrictions on the harvest of European Sturgeon could greatly increase the demand for and the price of Kentucky Paddlefish caviar.

While encouraging, the results of this investigation do not point to lucrative incomes being earned by polyculture paddlefish farmers using pond production. As a result, further study is suggested. Again, paddlefish are native to Kentucky, hence thrive in Kentucky's lakes and reservoirs. Future research efforts will focus on evaluating the economic viability of a commercial paddlefish industry based on large bodies of water, specifically reservoir ranching.

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Table 1: Production and Ownership Costs for a 12 Acre Pond Unit[1]

Production Costs	
Monoculture Production Costs	
Labor	3,822
All Terrain Vehicle Fuel, Oil, Lubrication, and Repair	560
Tractor Fuel, Oil, Lubrication, and Repair	834
Electricity	2,016
Levee Repair and Maintenance	2,200
Well Operation	720
Disease Control	960
Telephone	100
Supplies	350
Insurance	150
Interest 9 Months	2,648
Subtotal	14,360
Added Production Costs if Polyculture Catfish	
Fingerlings	4,050
Feed	16,335
Subtotal	20,385
Total Production Costs	
Monoculture Paddlefish (oppcost in Equation 3)	14,360
Polyculture Paddlefish and Catfish (oppcost in Equation 3)	34,745
Ownership Costs	
Equipment	1,170
Ponds and Land	5,750
Annual Depreciation	8,002
Taxes	120
Total Ownership Costs (capcost in Equation 3)	15,042

1. Information obtained from Stone, Nathan, Carole Engle, and Robert Rode. "Costs of Small-Scale Catfish Production." University of Arkansas. Division of Agriculture. Cooperative Extension Service. <http://www.uaex.edu/aquaculture2/FSA/FSA9077.htm> 26 July 1999.

Table 2: Returns to Mono and Polyculture Paddlefish Production In Kentucky.

Schedule	Avg. Prices	High P_m High Pr	High P_m Low P_r	Low P_m High Pr	Low P_m Low P_r
	Pm=6, Pr=42	Pm=12, Pr=84	Pm=12, Pr=21	Pm=3, Pr=84	Pm=3, Pr=21
Monoculture Production of Paddlefish					
1	-1,997,914	-1,997,914	-1,997,914	-1,997,914	-1,997,914
2	-1,997,914	-1,997,914	-1,997,914	-1,997,914	-1,997,914
3	-1,997,914	-1,997,914	-1,997,914	-1,997,914	-1,997,914
4	-1,997,914	-1,997,914	-1,997,914	-1,997,914	-1,997,914
5	-1,997,914	-1,984,792	-1,984,792	-1,997,914	-1,997,914
6	-1,997,914	-1,939,772	-1,939,772	-1,997,914	-1,997,914
7	-1,873,319	-1,707,518	-1,847,443	-1,816,294	-1,956,219
Polyculture Production of Paddlefish and Catfish					
1	273,369	878,818	878,818	-29,355	-29,355
2	-33,226	260,565	260,565	-180,121	-180,121
3	-135,659	54,776	54,776	-230,877	-230,877
4	-187,478	-49,221	-49,221	-256,606	-256,606
5	-218,312	-111,046	-111,046	-271,945	-271,945
6	-238,077	-150,637	-150,637	-281,797	-281,797
7	-159,645	6,156	-133,769	-102,620	-242,545

Note: Pm = Price of paddlefish meat. Pr = Price of paddlefish roe.

1. For comparison to the optimum (polyculture production with annual harvest), the model is restricted to require construction of the maximum number of ponds (5). This results in the negative numbers reported in this table. Had the model been unrestricted, all reported negative values would have been zero.