Economics and Marketing of Cryopreserved Fish Sperm

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"Frosty," the first calf born from the application of frozen sperm, is often credited for initiating the use of cryopreserved sperm in artificial insemination (AI) programs for dairy cattle. Although research into sperm cryopreservation had been documented almost 50 yr prior, Frosty represented an application of the technology with immediate commercial potential (Herman 1981). Since that time, frozen bull semen has been adopted by AI programs worldwide due to in part to economic benefits such as increased availability of semen and reduced transportation and holding costs.

We can consider the developmental chronology of mature markets for dairy bull sperm as a theoretical trajectory of the market life cycle for cryopreserved fish sperm (Figure 1). The current position on this trajectory indicates a market for fish sperm somewhere beyond conception (based on 40 yr of prior research) and before infancy (early stages of commercialization). What impetus will be required for commercial expansion of cryopreservation with the gametes and embryos of aquatic species? Is it realistic to rely on the emergence of an aquatic equivalent of Frosty? Indeed, fish have been produced experimentally with cryopreserved sperm for over 40 yr, yet no viable markets for frozen sperm currently exist for applications in fisheries and aquaculture.

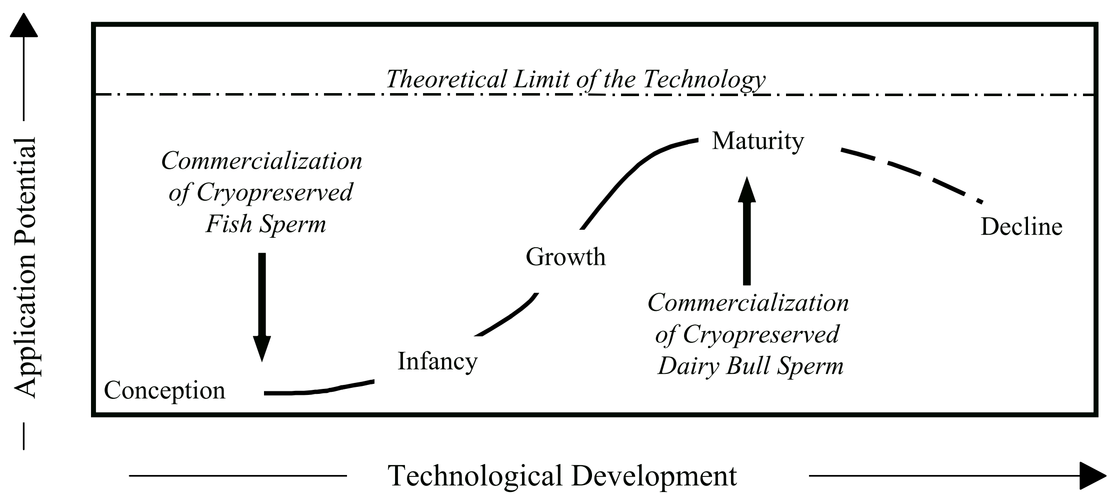

Figure 1. Conceptualized market life cycle for application of technology. Cryopreservation of dairy bull sperm is an example of a mature technology, while the commercialization of fish sperm cryopreservation is currently somewhere between conception and infancy (Adapted from Roussel et al. 1991).

In this chapter we discuss some primary economic constraints to the commercialization of sperm cryopreservation for use with aquatic species. Specifically, we review a recent economic study that outlines the basic costs required to integrate sperm cryopreservation into existing fish hatcheries (Caffey and Tiersch 1999). Until recently, such basic information had never been documented, although it is crucial for a

Caffey, R. H. and T. R. Tiersch. 2000. Economics and Marketing of Cryopreserved Fish Sperm. In: *Cryopreservation in Aquatic Species*. Tiersch, T. R. and P. M. Mazik, Editors. World Aquaculture Society, Baton Rogue, Louisiana. Pp. 388-408.

realistic evaluation of the feasibility of cryopreservation with the gametes and embryos of aquatic species. Based on this economic data and drawing again from the dairy bull model, we provide some preliminary marketing criteria that may be useful for identifying aquatic species where commercialization of cryopreserved sperm is most likely. These criteria provide the framework for a brief case study intended to illustrate how commercialization of research protocols for one application might provide impetus for future markets in cryopreserved fish sperm. Finally, we conclude with a discussion of some conceivable scenarios of the structure and development of future markets for cryopreserved fish sperm.

Economic Considerations: How Much Does it Cost?

A question frequently asked of the cryopreservation practitioner is *"How much does it cost?"* This simple query is becoming increasingly valid as the technology moves out of research and into application with aquatic organisms. However, the question is often difficult to answer, possibly because of variation in protocols, among and within species. Despite the lack of standardization, most methods share similar equipment and common procedures. A representative model of the generic characteristics of sperm cryopreservation with aquatic species may be useful for addressing fundamental economic considerations.

A Generic Model

In a recent study, we developed partial budgets for the integration of sperm cryopreservation into existing fish hatcheries (Caffey and Tiersch, in press). This involved the delineation of generic activities common to programs of fish sperm cryopreservation (Figure 2).

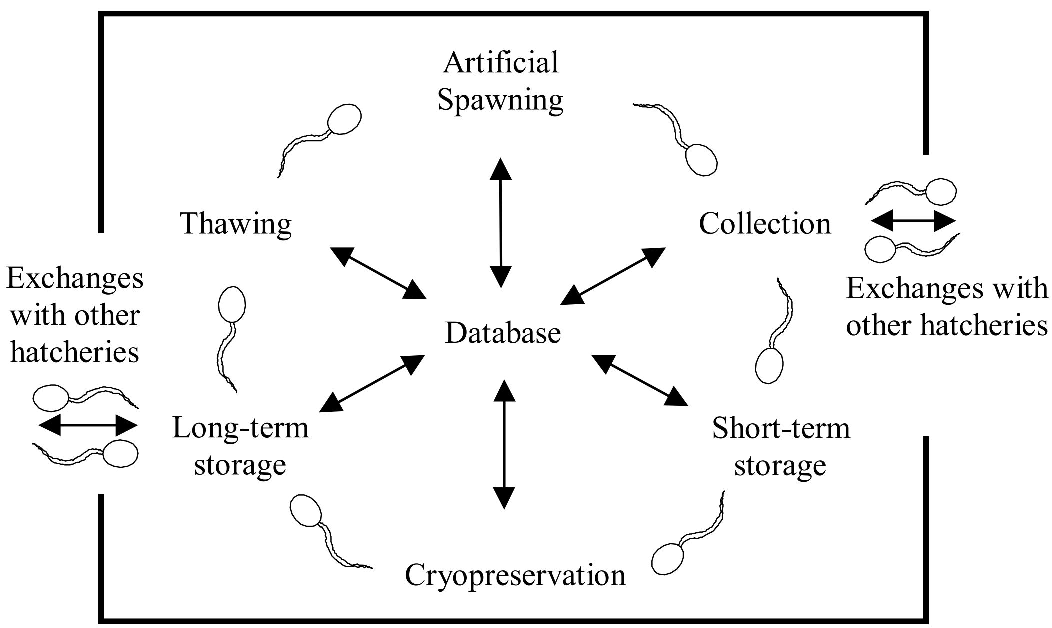

Figure 2. Generic activities of fish sperm cryopreservation. Consecutive components are delineated by a clockwise flow of sperm and two-way arrows are used to indicate maintenance of a centralized database for information on motility, fertilization, and inventory.

Specific activities include: 1) on-site and field collection of sperm; 2) short-term storage (refrigeration); 3) cryopreservation; 4) long-term storage; 5) thawing, and 6) artificial spawning. Two-way arrows represent information collected during each activity and stored in a centralized database.

Integration Scenarios

To employ the generic model for cost estimation, we must first identify the equipment and supplies utilized at each stage of the cryopreservation process. However, some of these items are not exclusive to cryopreservation and may be found at a given hatchery depending on its range of effort. Additionally, methods for fish sperm cryopreservation range from inexpensive and simple to costly and complex. Therefore, the costs of investing in cryopreservation ultimately depend on the current scope of a hatchery (i.e. equipment on hand) and the level of sophistication desired for a cryopreservation program (e.g. from pure production to pure research). Costs within this range are further defined by whether the hatchery is privately owned or publicly operated.

Few private fish hatcheries currently utilize sperm cryopreservation; yet commercial application should increase, as protocols are refined. However, public hatcheries are often financed by state or federal budgets and have the resources to invest in projects with undocumented technical and economic feasibility. Public hatcheries considering this technology may include a broader range of effort, ranging from small state-run hatcheries servicing put-and-take fisheries, to large-scale research hatcheries such as the Regional Fish Technology Centers operated by the U.S. Fish and Wildlife Service.

Budgeting Assumptions

The costs of equipment and supplies for fish sperm cryopreservation can be estimated using a modified partial budgeting procedure. Partial budgeting is traditionally used to estimate the commercial effects on costs and returns resulting from changes in management, investment, or technology (Shang 1990). Because fish sperm cryopreservation is currently non-commercial, budgeting information is limited to the cost data generated at public institutions. Our study abbreviated the traditional partial budget into a cost-analysis of the investment and operating expenditures necessary for implementing sperm cryopreservation at public and private fish hatcheries.

Physical Capacity

Developing the generic budget required assumptions. For example, the species-independent analysis precluded estimation of fertilization units. Instead, "production units" were defined in the budget as single, 0.5-mL straws of frozen sperm. Straws of this size are commonly used in fish sperm cryopreservation and with the sperm of other animals such as cattle. Setting a standard size for production units allowed extrapolation of those costs directly related to storage capacity. Capital and operational costs were generated for each component of the generic activity model (Figure 2) and expressed for public and private hatcheries at three levels of production (3,000, 6,000 and 9,000 units) which represented the purchase of three levels of storage capacity (1, 2 or 3 35-L storage dewars).

Financial Assumptions

Miscellaneous costs were defined in investment and operating budgets as 5% of budgeted items. Equipment depreciation was charged as facility maintenance and calculated using a straight-line method at 10% per yr with no salvage value. For this analysis, private hatcheries were assumed to finance their initial investment with an 5-yr intermediate loan at a 10% annual percentage rate (APR) and a charge of 12% APR for operating capital. Private hatcheries were also assumed to pay an 8% local sales tax on all purchases. All prices (reported in $US) represent the mean of three commercial estimates collected from equipment and supply vendors in 1999 (i.e. Parsons Air-Gas, Southland Cryogenics, Tech Air, Sigma, Scientific Products, Curtis Matheson Scientific and VWR Scientific).

Budgeting Results

The following synopsis provides summary information only. For additional information readers are encouraged to review Caffey and Tiersch (1999).

Investment Costs

Investment costs were classified as required or optional to the cryopreservation process (Table 1). Required equipment included items used exclusively for cryopreservation, storage and transport of fish sperm. Total investment for the required equipment ranged from $5,460 to $10,458 for public hatcheries and from $9,497 to $18,190 for private hatcheries.

Optional equipment included items that enhance quality control in the production of cryopreserved fish sperm. The most expensive item was the controlled-rate freezer. This device allows precise control of freezing rates and offers the greatest benefit to research, but would be useful where quality control is required. Total investment for required and optional equipment ranged from $37,290 to $42,288 (public), and $63,039 to $71,488 (private) for production capacities of 3,000 to 9,000 straws.

Operating Costs

Annual operating costs were estimated for production capacities of 3,000, 6,000 or 9,000 straws per yr (Table 2). Chemical expenditures represented a significant portion of the operating budget. For extenders, reagent-grade chemicals were included to provide ingredients sufficient to mix 50 L of Hanks' balanced salt solution (HBSS). Variations of HBSS have been used successfully with the sperm of multiple fish species (e.g. Tiersch et al. 1997) and these same ingredients can be used to formulate many other extenders used for fish sperm. Four commonly used cryoprotectants were budgeted: 1) dimethyl sulfoxide (DMSO); 2) dimethyl acetamide (DMA); 3) methanol, and 4) glycerol. Extracellular cryoprotectants such as egg yolk and milk are also commonly used, but their costs were negligible. Labor represented the largest single component of operating costs in the analysis. We assumed the use of a part-time technician at $10 per hr for manual filling and freezing of straws. However, labor costs would decline if automated straw fillers and freezers can be adopted from their use in the cryopreservation of bovine sperm. Annual operating costs ranged from $4,768 to $10,608 (public), and $5,768 to $12,831 (private) for straw capacities of 3,000 to 9,000 production units.

Table 1. Capital costs for integrating cryopreservation into existing fish hatcheries.

Item	Unit price	Storage capacity (0.5-mL straws) 3,000	6,000	9,000
Required equipment				
Storage dewar (35-L, high capacity)	$945	$1,890	$2,835	$3,780
Roller base for storage dewars	160	320	480	640
Low-level alarms (storage dewars, 115 v)	435	870	1,305	1,740
Shipping dewar (4.3-L, spill proof)	565	1,130	1,695	2,260
Cases for shipping dewars	275	550	825	1,100
Transfer hose and phase separator	190	190	190	190
Thermometer (digital, hand-held, +/- 100^{o}C)	250	250	250	250
Subtotals		$5,200	$7,580	$9,960
Miscellaneous (5%)		260	379	498
Sales tax (8%)		437	637	837
Interest on capital (10%)		3,600	5,248	6,895
Total investment (required equipment only)	Public	$5,460	$7,959	$10,458
	Private	$9,497	$13,843	$18,190

Table 1 Continued. Capital costs for integrating cryopreservation into existing fish hatcheries.

Item	Unit price	Storage capacity (0.5-mL straws) 3,000	6,000	9,000
Optional equipment				
Pipetor (1-10 μL)	227	227	227	227
Pipetor (10-100 μL)	227	227	227	227
Pipetor (100-1000 μL)	227	227	227	227
Water Bath (8-16 L, temperature to 90^{o}C)	1,212	1,212	1,212	1,212
Analytical balance (0.01 g readability, 1500 g max)	1,249	1,249	1,249	1,249
Data logger (hand-held, 5 inputs)	1,350	1,350	1,350	1,350
Distilled water source (2L per hr)	1,460	1,460	1,460	1,460
Vapor pressure osmometer (0-200 mOsmol/Kg)	4,681	4,681	4,681	4,681
Laboratory microscope (dark-field, 200-X)	7,181	7,181	7,181	7,181
Controlled-rate freezer	12,500	12,500	12,500	12,500
Subtotals		$35,514	$37,894	$40,274
Miscellaneous (5%)		1,776	1,895	2,014
Sales tax (8%)		2,983	3,183	3,383
Interest on capital (10%)		22,766	24,291	25,817
Total investment (required and optional equipment)	Public	$37,290	$39,789	$42,288
	Private	$63,039	$67,263	$71,488

Table 2. Annual operating costs for integrating cryopreservation into existing fish hatcheries.

Item	Unit price	Storage capacity (0.5-mL straws)		
		3,000	6,000	9,000
Straws (0.5-mL)	0.06	180.00	360.00	540.00
Goblets	0.26	156.00	312.00	468.00
Canes	0.21	16.38	32.76	49.14
Sealing powder (PVC, 1 Kg)	42.00	13.99	28.14	42.00
Ingredients for HBSS (ACS grade, 500 g of each)				
$NaCl$	23.38	7.72	15.66	23.38
KCl	23.13	7.63	15.50	23.13
$CaCl_2 \bullet 2H_2O$	48.50	16.01	32.50	48.50
$MgSO_4 \bullet 7H_2O$	45.24	14.93	30.31	45.24
Na_2HPO_4	38.65	12.75	25.90	38.65
KH_2PO_4	35.81	11.82	23.99	35.81
Na_2HCO_3	16.32	5.39	10.93	16.32
$C_6H_{12}O_6$	21.74	7.17	14.57	21.74
Cryoprotectants (500 mL of each)				
Dimethyl sulfoxide (DMSO)	50.00	16.50	33.50	50.00
Dimethyl acetamide (DMA)	50.00	16.50	33.50	50.00
Methanol	50.00	16.50	33.50	50.00
Glycerol	50.00	16.50	33.00	50.00
Liquid nitrogen	116.00	459.36	932.64	1392.00

Table 2. Continued. Annual operating costs for integrating cryopreservation into existing fish hatcheries.

Item	Unit Price	Storage capacity (0.5-mL straws) 3,000	6,000	9,000
Tank rental	37.33	37.33	37.33	37.33
Cryovials (1.2-mL, case of 500)	185.00	61.05	123.95	185.00
Centrifuge tubes (15-mL, case of 500)	148.33	48.95	99.38	148.33
Centrifuge tubes (50-mL, case of 500)	195.67	64.57	131.10	195.67
Microcentrifuge tubes (1.5-mL, pack of 1000)	40.37	13.32	27.05	40.37
Pipettor tips (small, pack of 1000)	47.07	15.53	31.54	47.07
Pipettor tips (large, pack of 1000)	56.00	18.48	37.52	56.00
Sterile filters (0.22-µm; case of 12)	56.80	18.74	38.06	56.80
Disposable sterile bottles (500-mL, case of 100)	56.20	18.55	37.65	56.20
Type-T thermocouples	31.67	63.34	126.68	190.02
Cryo gloves	100.67	201.34	201.34	201.34
Safety goggles	7.67	15.34	15.34	15.34
Labor				
Technician (per hr)	10.00	2400.00	3600.00	4800.00
Facility maintenance	0.10	589.68	859.57	1129.46
Subtotals		$4541.37	$7334.90	$10102.84
Contingency (5%)	0.05	227.07	366.75	505.14
Sales tax (8%)	0.08	381.47	616.13	848.64
Interest on operating capital (12%)	0.12	617.99	998.13	1374.80
Annual operating costs	Public	$4,768.43	$7,701.65	$10,607.99
	Private	$5,767.90	$9,315.91	$12,831.42

Per Unit Costs

In general, as production capacity increases, per unit costs decrease until production is maximized for a given level of technology. A per unit analysis can be used to identify economies of scale for various production capacities. For example, Tisdell et al. (1993) used per unit analyses to identify scale economies for seed production of the giant clam *Tridacna gigas*.

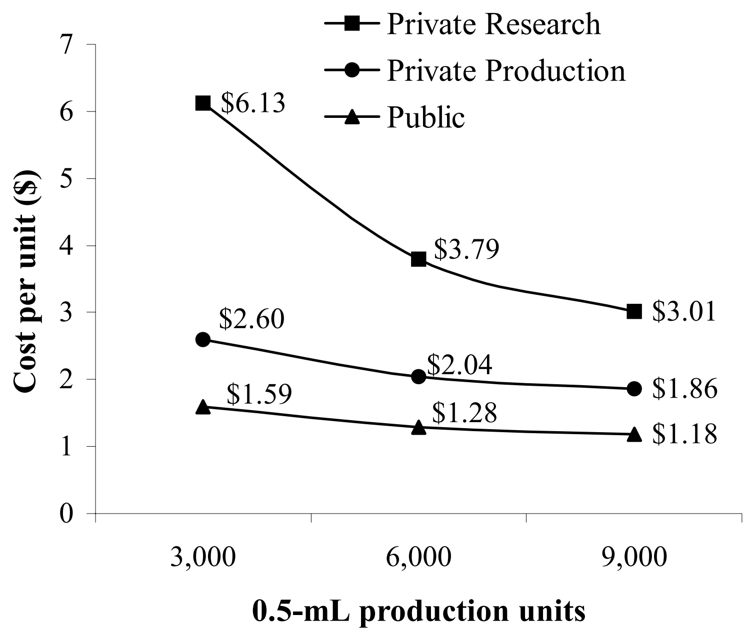

Figure 3. Costs per production unit for cryopreserved fish sperm.

Per unit costs for maximum production capacities of 3,000, 6,000 and 9,000 straws were expressed for three scenarios: 1) total annual costs of private hatcheries investing in required and optional equipment (identified as Private Research); 2) total annual costs of private hatcheries investing in required equipment (Private Production), and 3) operating costs at public hatcheries (Public) (Figure 3). In each case, negatively sloped cost curves indicate economies of scale at increased production levels. Private Research hatcheries exhibited the greatest per unit cost reductions for expanded production capacities. The per unit costs for these hatcheries was $6.13 per straw at 3,000 units, but as production capacity expanded to 9,000 units, per unit costs fell to $3.01 per straw. By comparison, Private Production hatcheries had substantially lower per unit costs because of their lower initial capital investment. These facilities had costs ranging from $2.60 per straw (3,000 units) to $1.86 per straw (9,000 units). Finally, per unit costs for Public hatcheries were calculated using operating expenditures only. Public hatcheries do not typically borrow funds to finance such projects and thus annual costs contain no amortization of initial investments. Accordingly, per unit costs for Public hatcheries were lowest of all, ranging between $1.59 per straw (3,000 units) to $1.18 per straw (9,000 units).

Summary of Generic Cost Analysis

Commercial hatcheries implementing a cryopreservation program can expect to spend as much as 70% more on initial investment and 20% more on annual operating costs compared to public hatcheries. This higher cost structure is due to sales tax and interest, which can account for over 50% of the final investment of private hatcheries. As production expands beyond a given storage capacity, private hatcheries can expect associated increases in required equipment expenditures such as for storage. However, purchases of optional equipment only serve to improve quality control potential and such equipment can increase initial costs by as much as 300%, while yielding no additional output.

Within the boundaries of pure production and pure research, individual fish hatcheries implementing a cryopreservation program would incur costs specific to the scope of their facility. For example, small-scale commercial fish hatcheries are often production-oriented, placing no effort in research. Cryopreservation programs established at these hatcheries would probably utilize required equipment only. Conversely, large state or federal hatcheries interested in developing a research-oriented cryopreservation program might have much of the required and optional equipment on hand, and thus a research program could be established for a lower investment.

Economies of scale were identified for increased production in three scenarios. Expanding the production of cryopreserved fish sperm at these hatcheries from 3,000 to 9,000 units resulted in per unit cost reductions of 25% to 70% (private research), 27% (private production) and 23% (public hatcheries). However, it is important to note that per unit costs in this analysis represent the minimum cost per straw possible for three levels of maximum storage and production capacity. An individual hatchery's cost structure and annual production of cryopreserved sperm will ultimately determine the actual per unit costs.

To summarize, it is logical that public fish hatcheries will be more likely to invest in cryopreservation in the near future because of lower investment costs and their insulation from the economic risks associated with new technology. However, increased commercialization of cryopreserved fish sperm can be expected as public hatcheries refine protocols and apply them in the private sector. Commercial adoption will develop when cryopreserved sperm becomes more cost-effective than traditional spawning methods for individual species.

Marketing Considerations

In the analysis above, we discuss the basic costs associated with fish sperm cryopreservation on a generic level. Further estimation of these costs for a particular species requires additional information on broodstock collection and holding costs, sperm production rates, sperm-to-egg application ratios, fertilization rates for fresh vs. cryopreserved sperm and dilution ratios for extenders and cryoprotectants. Such parameters coupled with estimates of potential genetic gain for specific production traits will ultimately define the commercial feasibility of cryopreservation with aquatic species. However, species-specific analyses are time consuming and a more generalized approach may be useful for the preliminary identification of those applications where the technology poses the greatest commercial potential.

Recognizing Market Potential

Simple observations on the early days of cryopreservation in the dairy industry may provide insight on how and where markets for fish sperm might develop. For example, the advent of cryopreserved bull sperm occurred in a dairy industry that already had significant economic impact in the 1950's. For this industry to adopt cryopreserved bull semen, the applications had to be technically feasible – and it had to work well for people to use it. Finally, the use of cryopreserved dairy bull semen was probably facilitated because of the dairy industry's dependence on artificial insemination. Used collectively, these rudimentary observations form useful criteria for evaluating the marketing potential of cryopreserved sperm with aquatic species.

Eel, Catfish, or Salmon?

Consider the economic impact of three aquatic species: European eel *Anguila anguila*, channel catfish *Ictalurus punctatus* and Atlantic salmon *Salmo salar*. The European eel has an established market worldwide and is readily cultured in France, Italy and Spain. The channel catfish is the single largest aquaculture commodity by value in the U.S., and the Atlantic salmon is a highly prized market fish produced in Norway, British Colombia, Chile and elsewhere (Avault 1996). Using a checklist format (Table 3) we confirm that each of these species has considerable economic impact. However, technical feasibility of reproduction using cryopreserved sperm has only been documented for two of the species (channel catfish and Atlantic salmon). Furthermore, there is good reason to believe that industry utilization of cryopreserved sperm in the near future is only likely with one of these species, Atlantic salmon. We find support for this assertion by again considering the market development for cryopreserved dairy bull sperm.

Table 3. Criteria for marketing of cryopreserved fish sperm.

Critieria for marketing cryopreserved fish sperm	Species		
	European eel	Channel catfish	Atlantic salmon
Economic impact	Yes	Yes	Yes
Technical feasibility	No	Yes	Yes
Industry utilization	No	No	Maybe

From Artificial Insemination to Artificial Spawning

Would the technical feasibility of frozen sperm have been sufficient impetus for the dairy industry to begin utilizing cryopreservation in the 1950's? Obviously, the product had to work and do so cost-effectively. However, the pre-existing infrastructure of artificial insemination appears to have facilitated adoption because reproductive technicians in the dairy industry were already accustomed to collecting, transporting, storing and using sperm.

Consider again production of channel catfish. Despite the fact this industry has tremendous economic impact and reproduction with cryopreserved sperm is technically feasible (Tiersch et al. 1994), producers may be unwilling to utilize cryopreservation because of their reliance on an extensive pond-based spawning regime developed and refined over the past 60 yr. Switching to cryopreserved sperm of channel catfish would allow for some advantages, such as increased control in genetic selection programs; however, such a transition would mean a drastic departure from established methods of reproductive management, a remote prospect for this industry in the near future.

Conversely, Atlantic salmon producers may be more amenable to the prospect of cryopreservation. In this industry, shore-based hatcheries produce seedstock by manual stripping of gametes for fertilization and hatching. This human intervention in the reproductive process of fish is typically known as artificial spawning and it is analogous to the artificial insemination methods of the dairy industry prior to the advent of cryopreservation.

Compared to pond-based spawning regimes such as those in the channel catfish industry, adoption of cryopreserved sperm for use in established artificial spawning programs represents a less drastic technological shift for improving aquatic reproduction. If the dairy model provides any indication, the logical beginning for sperm cryopreservation is with those aquatic species currently produced by artificial spawning methods.

The Case of Hybrid Striped Bass Production

Hybrid striped bass of the genus *Morone*, represent aquaculture organisms with increasing economic impact where reproduction by cryopreserved sperm may be technically feasible. Furthermore, the production of hybrid striped bass (HSB) involves an artificial spawning regime that could benefit from cryopreservation if applications were proven to be cost-effective. A summary of this industry and a brief economic case study are provided to illustrate how commercialization of HSB research protocols might provide impetus for future markets in cryopreserved fish sperm.

Hybrid Striped Bass Background

United States production of HSB expanded over 900% in the 1990's, becoming one of the fastest growing segments of American aquaculture. Markets for HSB remain strong, but the industry is currently constrained by difficulties in the hatchery process. The hybridization of striped bass *Morone saxitilis* and white bass *Morone chrysops* is especially difficult because their spawning seasons only partially overlap and the fish are not always found in the same location. These constraints often limit hatchery production and can subject producers to shortages in seedstock. Kirby (1983, 1984) documented reproduction and growth of striped bass produced with cryopreserved sperm. More recently, additional research has been documented on the cryopreservation of sperm from striped bass and white bass (Brown and Brown, pp. 130-137, this volume).

Given the prospect of technical feasibility, it is plausible that cryopreserved sperm could yield economic benefits to HSB production. Such benefits might include a reduction in the temporal and spatial constraints of broodstock collection and spawning, expanding the time available for production of HSB seedstock and making hybridization more dependable while reducing hatchery costs. It is also worth noting that several state and federal hatcheries in the U.S. currently produce striped bass and hybrids for put-and-take fisheries. The availability of cryopreserved sperm could aid in reducing inbreeding in public hatchery stocks of striped bass and hybrids.

Setting up a Comparison

We have developed a hypothetical comparison for production of reciprocal hybrid striped bass production (female white bass x male striped bass) using fresh and cryopreserved sperm. Although production of reciprocal HSB requires additional steps (white bass eggs are adhesive and must be disaggregated before hatching), reciprocal hybrids are preferred by commercial producers because white bass females are typically easier to manage due to their smaller size and increased propensity for feeding in captivity (personal communication, Michael Freeze, Keo Fish Farm, Arkansas). Additionally, white bass eggs are small, having an egg number per unit spawn weight of ~ 4 times that of striped bass females (Harrell et al. 1990). These advantages are enhanced by the fact that reciprocal HSB production requires male striped bass, a fish known for producing copious amounts of sperm.

Table 4 lists general assumptions for comparing reciprocal HSB production using fresh and cryopreserved sperm. To begin, we arbitrarily set annual production at 80,000 Kg. Such a production level would require ~18 hectares of ponds assuming conservative stocking rates and an average harvest weight of 800 g per fish (100,000 fish at 2,000 Kg per hectares). With backwards extrapolation, we estimated the initial number of fry at 259,200, based on average mortality rates of 20% in Phase 3, 20% in Phase 2, and 80% in Phase 1. An estimate for the total number of fry does not necessarily translate to an equal number of eggs. Depending on ovulation rates, egg quality and handling, any particular spawn may be comprised of 0 to 100% of eggs that do not hatch. To account for this, we estimated egg demand at twice the total fry production. Therefore, based on 2,500 white bass eggs per g, a total of 250 g of eggs would be required for fry production (Harrell et al. 1990).

To determine the total volume of sperm required, we assumed a generous sperm-to-egg ratio of 1:10 (volume). For our case study, this ratio translates to a requirement of 25 mL of fresh sperm. Striped bass males used in HSB production typically average 2 to 5 Kg and a single large male could presumably supply all the sperm needed (50 mL). In this analysis we assumed that a minimum of ten males would be required to protect against mortality risks and to increase genetic variability. To estimate the amount of cryopreserved sperm we made some assumptions about its efficacy. Such estimates were difficult because sperm viability is only one of a variety of parameters that ultimately determine fertilization rates. For the sake of this study, we set the fertilization rate for cryopreserved sperm as 50% of the rate for fresh sperm. This translates to a doubling of the sperm requirement in the case for cryopreservation. We recognize that is a simple linear assumption and further analyses are required to address the economic requirements for additional eggs.

Table 4. Assumptions for comparison of fresh and cryopreserved sperm for production of reciprocal hybrid striped bass.

Annual production (Kg)	80,000
Area of farm (hectare)	18
Average harvest weight (g)	800
Total number of fish at harvest	100,000
Harvest weight (Kg/hectare)	2,000
Phase 3 mortality (%)	20
Phase 2 mortality (%)	20
Phase 1 mortality (%)	80
Total number of fry	259,200
Egg viability (%)	50
Number of eggs per g	2500
Total egg requirement (g)	250
Sperm:egg volume ratio	1:10
Total volume required for fresh sperm (mL)	25
Fertilization rate from frozen sperm (% of fresh sperm)	50
Total volume required for frozen sperm (mL)	50
Number of striped bass males	10
Sperm production per male (mL)	25
Total sperm collected (mL)	250
Sperm:extender volume ratio for cryopreservation	1:4
Cryopreservation straw size (mL)	5
Fresh sperm production units (useful/wasted)	25/225
Frozen sperm production units (useful/wasted)	125/0

Striped Bass Sperm: Fresh vs. Frozen

Returning to our chapter's initial question we now ask, *"how much does it cost to cryopreserve striped bass sperm?"* To answer this question, two things are needed: 1) an estimate of the generic costs required for fish sperm cryopreservation, and 2) a budget for broodstock collection of striped bass males. To begin, we return to Table 1 and consider a private cryopreservation program purchasing required equipment only. At the lowest level of storage capacity, total investment costs $9,497 or $1,900 per yr based on the 5-yr amortization schedule. Added to the yearly operating costs of $5,768, annual expenditures for the generic cryopreservation program would be $7,668 (Table 5).

Table 5. Annual costs for collection and storage of striped bass sperm (fresh and frozen) for production of reciprocal hybrid striped bass.

	Recruitment effort (# of trips)		
Item	**1**	**2**	**3**
Cryopreservation			
Fixed costs	$1,900	- -	- -
Operating costs	5,768	- -	- -
Subtotal	$7,668	- -	- -
Broodstock recruitment			
Guide fee ($250 per d)	250	500	750
Transportation (500 km @ $0.18/km)	90	180	270
Lodging ($75 per night)	75	150	225
Labor (2 people, 2 d, 8 hr per d, @$10 per hr)	320	640	1,280
Supplies	25	50	75
Total cost: fresh sperm	$760	$1,520	$2,600
Per unit cost (25 units)	$30	$61	$104
Total cost: frozen sperm	$8,428	- -	- -
Per unit cost (125 units)	$67	- -	- -

Secondly, we need to estimate the specific costs for the collection, transport and holding of striped bass males. Broodstock collection for HSB production is often coordinated with commercial guides, but recall that striped bass and white bass are not always available at the same time and location, therefore, costs for guided trips reflect only the costs for collecting striped bass males. Budget assumptions include a 500-km round trip at a $0.18 per km rate, a guide fee of $250 per d, $75 for lodging, $25 for supplies and $10 per hr for two employees working two 8-hr d (1 d fishing, 1 d transit). These costs are derived from similar expenditures incurred during our HSB hatchery and cryopreservation research at Louisiana State University.

Assuming all ten males are obtained in one trip, total costs associated for recruitment are $760 per yr. Adding this amount to the $7,668, costs for the cryopreserved striped bass sperm are estimated at $8,428 per yr. Compared to costs for fresh sperm, the increased costs of utilizing cryopreserved sperm may initially appear to negate any advantages associated with the technology. Yet, some additional considerations are required before we can realistically consider the cost-effectiveness of cryopreservation in this application.

The Hamburger Factor

The true advantages of fish sperm cryopreservation are illustrated in the obvious benefits of modern food refrigeration. For example, imagine having to slaughter a cow every time you wanted to eat a hamburger. Conversely, imagine having to justify the purchase of a freezer for the storage of only one hamburger patty. While these analogies may seem absurd, they serve to illustrate two important points. First, we must recognize that there is often a tremendous amount of sperm wasted during traditional methods of artificial spawning. In the case of striped bass, male fish frequently produce considerably more than the required amount of sperm. Secondly, it is not fair or realistic to evaluate the economic feasibility of fish sperm cryopreservation against the costs of a single broodstock recruitment trip. Multiple recruitment efforts are often required in artificial spawning regimes for the production of aquatic species. Similar problems particular to the production of HSB include: 1) failure to obtain the needed number of males; 2) failure to harvest ripe males at an early date (white bass spawn on average about 1 month earlier than striped bass) and, 3) failure to keep harvested males alive while waiting for female white bass to ovulate. A more realistic economic evaluation of cryopreserved sperm must account for the waste factor and the potential for multiple broodstock recruitment efforts.

Recall that only 25 mL of fresh sperm and 50 mL of frozen sperm was required to produce the needed amount of fish. However, a total of 250 mL of sperm would be available with a realistic collection rate of 25 mL from each of the 10 striped bass males. Thus, the "hamburger factor" is illustrated by a 25/225 ratio of useful/wasted production units under the traditional production scenario. Conversely, the ability to freeze sperm yields an extra 100 5-mL production units.

Expanding our comparison of fresh and cryopreserved sperm, we return to Table 5 and consider now the costs per production unit under a scenario of multiple recruitment trips. Recall that ten males were to be collected during a single collection trip. Under the cryopreservation scenario, annual costs are $8,428 or $67 per production unit. This cost is greater than $30 per unit for fresh sperm. However, a second or third recruitment effort increases the costs of fresh sperm to $61 and $104 per unit. In general, the per-unit costs of fresh sperm increase as recruitment effort increases (Figure 4). On a per unit basis, cryopreservation yields 125 production units compared to the 25 units available using fresh sperm. The opportunity costs associated with wasted sperm become increasingly evident as additional attempts at artificial spawning efforts are required.

Additional attempts at fertilization are not uncommon for artificial spawning and may be necessary because of a variety of problems such as inferior egg quality, improper techniques or larval mortality. Additionally, sperm quantity and quality from captive broodstock tends to deteriorate over time and broodstock mortality is not uncommon because of the stress-related aspects of capture, handling and holding. These problems often result in the need for multiple broodstock recruitment efforts within and across production seasons. Thus, the hamburger analogy is repeatedly revisited.

Summary of Hybrid Striped Bass Case Study

Our comparison of fresh and frozen sperm has no shortage of assumptions and we realize that such budgets can be constructed in many different ways, with minute changes in any one assumption providing different economic outcomes. However, the main purpose of this case study was not to develop discrete values, but rather to identify the primary economic variables needed for species-specific analysis and to illustrate the general relationships among parameters that affect economic feasibility. First, we assert that sperm cryopreservation for aquatic species is probably best suited for those applications in fisheries and aquaculture utilizing artificial spawning. In the case of HSB production, we specifically illustrate the need to compare the costs of frozen sperm under

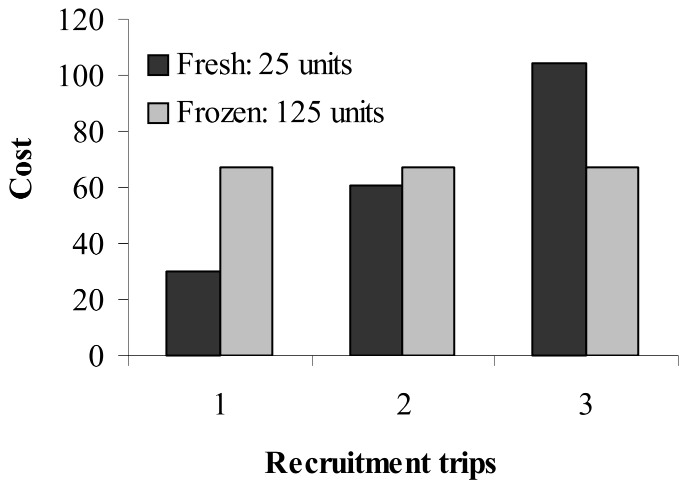

Figure 4. Cost per production unit for fresh and cryopreserved striped bass sperm.

realistic consideration of the waste factor associated with artificial spawning. Exactly how much sperm previously wasted could be collected and cryopreserved? The answer to this question will ultimately determine the number of available production units. In our analysis, 250 mL of striped bass translated to 125 cryopreserved productions units. However, this number could be higher or lower depending on variations in the total amount of collectible sperm, induced sperm production by use of hormones and variations in extender dilution rates.

Broodstock collection effort is perhaps one of the most critical aspects for determining the economic feasibility of cryopreserved fish sperm. In our case study we showed increasing feasibility for frozen sperm as collection efforts increased. However, the interpretation of collection is not limited to a single producer making one or more trips within a single yr. Additional interpretations might include a single producer with multiple recruitment trips across several years or multiple producers each requiring sperm within and across spawning seasons. Evaluating these alternative economic scenarios will reveal additional information on the economics of cryopreservation applications.

Future Considerations

Cooperatives

Despite the potential economic feasibility of fish sperm cryopreservation, the immediate costs associated with investment in the technology may be prohibitive for a single investor. Such cost constraints were encountered in the early days of the dairy industry when AI emerged as an economic reaction to the prohibitive costs of maintaining bulls.

Business structures such as partnerships and corporations are traditionally used for spreading out the costs and risks of commercial investments. Among the many types of business structures available for marketing of fish sperm, cooperatives may represent the most logical alternative. The unique advantages offered by cooperatives are inherent to their definition. A cooperative is typically defined as:

> "…a business voluntarily organized, operating at cost, which is owned, capitalized, and controlled by member patrons as users, sharing risks and benefits proportional to their participation" (Roy 1981).

By the late 1800's, U.S. dairy farmers were forming crude cooperatives known as "breeders clubs" (Herman 1981). These organizations were initially no more than small groups of dairymen who collectively supported the purchase and maintenance of bulls. This centralization assured dairymen would have the needed services of quality sires at reduced cost. Eventually the cooperative nature of these organizations facilitated the adoption of technological innovations such as artificial insemination in the early 1900's and cryopreservation in the 1950's. Today, many of these organizations have evolved into super-cooperatives that specialize in harnessing commercially desirable genetic gain by utilizing innovative technologies such as gamete cryopreservation and embryo transfer.

Cooperatives offer similar advantages for market development with cryopreserved fish sperm. Returning to the HSB example, the investment and operating costs for cryopreservation may be more affordable if spread over several commercial cooperative members whose risks and benefits are relative to their level of participation. Furthermore, a state-run cryopreservation cooperative for fish sperm could offer additional advantages of a lower cost structure and increased technical expertise. Such public cooperatives were quite successful in the formative days of AI and sperm cryopreservation in the dairy industry.

Non-Market Species

The focus of this chapter has been to identify constraints and solutions related to the economics and marketing of cryopreserved fish sperm in fisheries and aquaculture. However, fisheries and aquaculture constitute only half of the applications discussed in this text. The use of cryopreservation for sperm and embryo-based conservation of threatened and endangered (T & E) species is an area with considerable economic and market implications as well.

Non-market valuation techniques have emerged in recent years as the result of a paradigm shift in traditional economics. The shift occurred as increasing evidence mounted that neoclassical economic theory was insufficient for determining the value of non-exclusive and non-renewable resources (Costanza et al. 1997). A new branch of the discipline, environmental economics, utilizes non-market techniques for estimating externality costs (e.g. the cost of environmental pollution) and contingent, in-situ, and bequest values (e.g. the value of an endangered species). An environmental economics approach has already been applied in the area of T & E species by way of a contingent valuation method that estimates public willingness-to-pay (WTP) for conservation of a particular species (Walsh et al. 1984). Similar potential exists for deriving new WTP estimates of the value of cryopreserved gametes and embryos of T & E species. Such data might prove useful for validating the efforts of government fish hatcheries conducting cryopreservation-based conservation efforts or developing germplasm repositories. Eventually, market-based incentives for conservation could emerge in which direct or indirect payments are made by governments to commercial entities for cryopreservation of T & E species. Such market-based incentives have gained momentum in recent years due in large part to the failure of regulatory approaches to control the loss of natural resources from the ecosystem to species levels.

Conclusions

We conclude by reiterating some of the critical points we have outlined in this chapter (Table 6). Perhaps the most astounding point is that after 40 yr of research into fish sperm cryopreservation, there is only one documented report pertaining to the economic aspects of this technology (Caffey and Tiersch 1999). Any possibility of commercialization hinges on knowledge of the basic costs associated with application in aquatic species. The specificity of this economic information must increase for cryopreservation to advance beyond research and into commercial application with aquatic species. Preliminary generic cost analysis indicates that public hatcheries currently hold an advantage over private hatcheries trying to establish cryopreservation programs. Lower cost structure and increased insulation from economic risks could translate to a greater potential for cryopreservation investments being made at public hatcheries. Technology transfer by these facilities to the private sector would aid development and refinement of commercial protocols. Adoption of these protocols will require cost-effectiveness compared to traditional spawning methods. However, the technical feasibility of reproduction using cryopreserved fish sperm is commercially irrelevant in species without significant economic impact. Furthermore, it is most likely that commercial utilization of cryopreservation will occur in those aquatic species produced by artificial spawning.

A case study with HSB illustrates that the economic feasibility of fish sperm cryopreservation is ultimately a function of reducing waste and effort. How much previously wasted sperm can be cryopreserved? How can cryopreservation reduce the costs and risks associated with broodstock recruitment? What are the commercially relevant genetic traits of the culture species and to what extent can cryopreservation help us to capitalize on their heritability? As seen with the dairy industry, commercial development of markets for fish sperm would probably be enhanced by formation of producer cooperatives. Such organizations have facilitated the use of cryopreserved bull semen in the dairy industry by spreading out costs and risks and by reducing the technological constraints associated with cryopreservation.

Finally, this chapter has focused primarily on commercial applications of fish sperm cryopreservation for fisheries management and aquaculture; however, the use of this technology for conservation of T & E species is an area where environmental economics has much to contribute. Application of alternative economic valuation approaches such as WTP, may eventually be necessary for providing the economic values associated with non-market aquatic species and the justification for cryopreservation-based conservation efforts.

Table 6. Points for discussion regarding the economics and marketing of cryopreserved fish sperm.

Economic information is crucial for determining the feasibility of any application of cryopreservation.
Public fish hatcheries have lower barriers to cryopreservation investment because of their lower cost structure and existing technical expertise.
Market development hinges on refining the technical feasibility of reproduction via cryopreservation.
Technical feasibility of cryopreserved sperm is commercially irrelevant in species with little or no economic impact.
Artificial spawning is analogous to artificial insemination and constitutes a major requirement for commercial adoption of cryopreserved sperm in aquatic species.
Economic comparisons of fresh and frozen sperm should incorporate the opportunity costs of wasted sperm.
Economic comparisons of fresh and frozen sperm should incorporate the possibility of multiple recruitment efforts within and across production facilities and spawning seasons.
Cooperatives represent the most logical business structure for market development with cryopreserved fish sperm.
Public fish sperm cooperatives will initially offer the greater advantages for industry development with aquatic species.
There is much potential for environmental economists to evaluate the costs and values of cryopreservation-based conservation with threatened and endangered species.

Acknowledgements

Supported in part by grants from the United States Department of Agriculture. Approved for publication by the Director of the Louisiana Agricultural Experiment Station as manuscript number 98-66-0226.

References

Avault, J. W. 1996. Fundamentals of Aquaculture. AVA Publishing Company, Inc. Baton Rouge, Louisiana.

Caffey, R. H. and T. R. Tiersch. 1999. Cost analysis for integrating sperm cryopreservation into existing fish hatcheries. Journal of the World Aquaculture Society. In press.

Costanza, R., R. d'Arge, R. deGroot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton, and M. van de Belt. 1997. The value of the World's ecosystem services and natural capital. Nature 387:253-260.

Harrell, R. M., J. H. Kerby and R. V. Minton. 1990. Culture and Propagation of Striped Bass and its Hybrids. Striped Bass Committee, Southern Division, American Fisheries Society, Bethesda, Maryland.

Herman, H. A. 1981. Improving Cattle by the Millions. University of Missouri Press, Columbia, Missouri.

Kirby, J. H. 1983. Cryogenic preservation of sperm from striped bass. Transactions of the American Fisheries Society 112:86-94.

Kirby, J. H. 1984. Cryopreservation of striped bass spermatazoa: Problems and progress. *In*: The Aquaculture of Striped Bass: A Proceedings. J. P. McCraren, editor. Maryland Sea Grant Publication UM-SG-Map-84-01. University of Maryland, College Park, Maryland. Pp. 205-213.

Roussel, P., K. Saad and T. Erickson. 1991. Third Generation R & D: Managing the Link to Corporate Strategy, Authur Little Inc., Boston, Massachusetts.

Roy, E. P. 1981. Cooperatives: Development, Principles, and Management. Interstate Printers and Publishers, Inc., Danville, Illinois.

Shang, Y. C. 1990. Aquaculture Economic Analysis: An Introduction. *In*: Advances in World Aquaculture, Volume 2. World Aquaculture Society, Baton Rouge, Louisiana.

Tiersch, T. R., C. A. Goudie and G. J. Carmichael. 1994. Cryopreservation of channel catfish sperm: Storage in cryoprotectants, fertilization trials, and growth of channel catfish produced with cryopreserved sperm. Transactions of the American Fisheries Society 123:580-586.

Tiersch, T. R., W. R. Wayman, C. R. Fiegel, O. T. Gorman, J. H. Williamson and G. J. Carmichael. 1997. Field collection, handling, and storage of sperm of the endangered razorback sucker. North American Journal of Fisheries Management 17:167-173.

Tisdell, C. A., W. R. Thomas and L. Tacconi. 1993. The cost of production of giant clam seed (*Tridacna gigas*). Journal of the World Aquaculture Society 24:352-360.

Walsh, R. G., J. B. Loomis and R. A. Gillman. 1984. Valuing option, existence, and bequest demands for wilderness. Land Economics Volume 60, No. 1.