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THE BIOECONOMIC FEASIBILITY OF CULTURING TRIPLOID *CRASSOSTREA ARIAKENSIS* IN NORTH CAROLINA

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ABSTRACT The collapse of the native oyster *Crassostrea virginica* fishery along the eastern United States has prompted resource managers to consider introducing a nonnative oyster for restoration of the wild fishery and/or for culture as a nonreproductive triploid. Evaluation of the profitability of a medium-sized *C. ariakensis* culture operation (500,000 oysters per year on ~3 acre lease), assuming constancy of present market price despite increased supply, indicated that grow-out over winter resulted in an estimated ~27% to 29% return on the annual investment at salinities >10 ppt because survivorship was high and *Polydora* spp. infestation did not occur. The greater cost of a longer grow-out phase at intermediate (10–25 ppt) salinities compensated for slightly higher mortality rates at high (>25 ppt) salinity sites, such that profitability did not vary with salinity during winter. In contrast, operations in summer always lost revenue (–28 to –37% return on investment) because of higher mortality rates at high salinities and elevated *Polydora* spp. infestation rates at intermediate salinities rendering the blistered oysters unsuitable for the half-shell market. Solving both the *Polydora* and survivorship problems would suffice to render summer operations profitable. Purchase of larger (>25 mm SH) seed from hatcheries reduced the return on investment by ~60% in comparison with purchase and further nursery rearing of smaller (3 mm SH) seed in 2-mm mesh bags at the grow-out site. Operations utilizing larger seed were, however, still profitable (11% to 12% return on investment) during winter grow-out, and are less risky than including a nursery phase. Although *Polydora* infestation did not occur during the winter, sensitivity analysis determined that culture operations are extremely sensitive to *Polydora* spp. infestation. For instance, our analyses suggest that operations with infestation rates greater than 54% would lose revenue. Therefore, growers must avoid extending production especially at intermediate-salinity sites where grow-out is slower into the summer months when *Polydora* spp. settlement typically occurs. Given the economic viability of culturing *C. ariakensis* oysters, the potential value of the aquaculture fishery must now be considered in a broader context of the economic and ecosystem risks and benefits associated with introducing a nonnative oyster versus not introducing but instead restoring the native oyster.

KEY WORDS: *Crassostrea ariakensis*, *Crassostrea virginica*, economic feasibility, mud blisters, native vs. non-native oysters, oyster disease, oyster growth, oyster survivorship, *Polydora* spp., triploid

INTRODUCTION

With the collapse of eastern oyster *Crassostrea virginica* (Gmelin 1791), fisheries throughout the estuaries of the eastern United States have had severe ecological and socioeconomic consequences (Frankenberg 1995, MacKenzie 1996, Coen et al. 1999, Peterson et al. 2003). Commercial fishermen who once depended on oyster harvesting as an important source of income have been forced to harvest other species or seek alternate employment. Degradation of oyster reefs via destructive harvesting practices as well as overfishing, oyster disease, sedimentation, and water quality degradation has reduced the quantity of available reef habitat, which augments juvenile fish and crustacean production in estuaries (Rothschild et al. 1994, Coen et al., 1999, Peterson et al. 2003, Grabowski et al. 2005). Removal of filter-feeding oysters from estuaries such as in the Chesapeake Bay and the Pamlico Sound has resulted in trophic restructuring that promotes pelagic and planktonic organisms over benthic flora and fauna (Newell 1988, Ulanowicz & Tuttle 1992, Paerl et al. 1998, Jackson et al. 2001, Baird et al. 2004). In North Carolina, annual oyster harvests are less than 1% of the historic maxima even though restoration efforts aimed at bolstering landings have been conducted over the past several decades (Frankenberg 1995). Given that oyster diseases are the proximate cause of much of the mortality, the commercial fishing industry has advocated the introduction of a disease-resistant, nonnative oyster to revitalize the economic viability of oyster fisheries in Maryland, VA, and North Carolina (Mann et al. 1991, Byrne 1996). This is a highly controversial action requiring a complete consideration of potential risks and benefits (National Research Council 2003).

The history of species introductions is generally poor such that introduced species are now one of the greatest threats to the sustainability of ecosystem services worldwide (Carlton 1992). Even well planned intentional introductions often have failed because ecology as a science is sorely challenged to yield accurate predictions. Shellfish (oysters especially) introductions have resulted in both positive and negative results. Prior introductions of nonnative oysters elsewhere in the United States have established valuable fisheries, but are also believed to be responsible for introducing the oyster disease, *Perkinsus marinus*, that has inhibited restoration of eastern oyster populations in recent decades (Burreson & Calvo 1996, Ford 1996). Following the International Council for the Exploration of the Sea (ICES) protocols on introducing species for fisheries would prevent many past problems from being repeated. However, evolutionary changes of introduced species have led to many examples of the failure of present ecology and physiology to predict the future accurately after exposure to new selective regimes through introduction (Simberloff 2005). For example, although thought to be sterile in colder waters typical of the waters around the San Juan Islands, *C. gigas* recently has begun

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to reproduce during culture grow-out and only now is successfully invading the intertidal habitats of the Pacific northwest even though it has been cultured for several decades (Padilla 2004). The history of introductions exemplifies the ecological risks associated with introducing nonnative species, so that future planned introductions should be preceded by careful consideration of all potential risks and benefits prior to taking action, including the economic consequences.

Although fisheries ecologists have evaluated the potential ecological risks associated with the introduction of *C. ariakensis* to estuaries of the eastern United States, concerns remain about the potential threat that these activities may pose to local and regional ecosystems (Mann 1979, Andrews 1980, Mann et al. 1991, Lipton et al. 1992, Byrne 1996, Gaffney et al. 1996, Gottlieb & Schweighofer 1996). The lack of information on the biology of *C. ariakensis* motivated the NRC Committee on Nonnative Oysters in the Chesapeake Bay to recommend further research to compare the biology of native to nonnative oysters (National Research Council 2003). Recent field trials in North Carolina and the Chesapeake have shown that triploid *C. ariakensis* outgrows the native oyster (Calvo et al. 2001, Grabowski et al. 2004). These studies have also documented that it is not susceptible to the protozoan parasite *Perkinsus marinus*, the disease that now kills such a large fraction of *C. virginica* before reaching market size, and its own unique susceptibility to mortality from *Bonamia* sp. can be countered by avoiding exposure of seed to *Bonamia*-infested waters. *C. ariakensis* survivorship rates in these previous studies have ranged from 56% to 90% at intermediate (10‰ to 25‰) and high (>25‰) salinities. Although high growth and survival rates coupled with low disease susceptibility suggest that culture of *C. ariakensis* could successfully revitalize the oyster fishery in the eastern United States, a bioeconomic evaluation of the profitability of oyster culture is needed to serve as a formal quantitative test of this suggestion.

The profitability of a culture operation is likely to be a function of season of grow-out and salinity. Oysters generally grow faster in the warmer months but can experience greater mortality from disease and predation (Grabowski et al. 2004, Bishop & Peterson 2005a). Season and salinity can also influence profitability by dictating levels of infestation of oysters by mud blisters (*Polydora* spp.) (Bishop & Peterson 2005a). Mud blister coverage on more than 25% of the surface of an oyster renders it unacceptable for sale on the higher-valued half-shell (i.e., oysters destined for consumption as individuals in the shell, either raw or steamed) market (Handley & Bergquist 1997), where oysters bring 3–10 times the price of oysters that are processed in shucking houses. Mud blister infestation causes a black discoloration on the inside of the shell that may burst when being shucked and inject shell fragments and mud into the meat portion. Given that triploid oysters typically require greater investment and production costs associated with culture than diploids (i.e., triploid seed are more costly and require laboratory testing for genetic reversion to diploidy), producing a high quality oyster that can be sold on the half-shell market may be critical in determining whether a culture operation is profitable.

Here we conduct a bioeconomic evaluation of the profitability of a medium-sized (500,000 oysters per year on a 3-acre lease) culture operation producing *C. ariakensis* in North Carolina. Specifically, we used biological performance data from Grabowski et al. (2004) and Bishop and Peterson (2005a) to assess how the salinity regimen, the season in which grow-out is conducted, and the size at which seed are purchased affect the profitability of culturing triploid *C. ariakensis*. Furthermore, we conducted sensitivity analyses to determine the degree to which the value of a culture operation is influenced by changes in seed price, operation size, market price, infestation by *Polydora* spp., and oyster survivorship.

METHODS

We assessed the bioeconomic feasibility of a medium-sized (i.e., 500,000 oysters per year on a ~3 acre lease) aquaculture operation of triploid *C. ariakensis* in North Carolina. The economic and biological data necessary for this study were collected from recent studies, interactions with numerous fishermen, and the North Carolina Department of Marine Fisheries on the biological performance (Grabowski et al. 2004, Bishop & Peterson 2005a) and palatability (Grabowski et al. 2003, Bishop & Peterson 2005b) of *C. ariakensis* grown in North Carolina waters. These data were incorporated into a spreadsheet model to quantify (1) investment costs; (2) production costs; (3) cash flow; (4) the annual enterprise budget (as per Adams & van Blokland 1998), and (5) the sensitivity of profitability to variation in seed price, operation size, market price, and rates of mud-blister infestation and survivorship during the first five years of operation. The relationship between price and survivorship was assumed to be purely linear for the purpose of this study, because we did not explore this potential interaction. Although the operation could be conducted in perpetuity, a five-year project duration was chosen because this is an adequate length of time to offset high initial investment costs and determine whether the venture is profitable.

Culture Production

Culturing oysters involves three phases. In the first (hatchery) phase, oyster growers induce spawning and egg fertilization and then rear subsequent offspring from larvae to ~3 mm (shell height [SH]) spat. In the second (nursery) phase, oyster growers raise these spat oysters that are highly susceptible to mortality from predatory crabs and gastropods to 25 mm SH in either upwellers or fine-mesh cages in the field. Finally, oysters are raised to edible (75 + mm SH) sizes during the grow-out phase. In this study we evaluated the final two stages of culture using cost-benefit analysis, but did not quantify the economic benefits and costs associated with the hatchery phase. To determine if a culture operation should include on-site nursery grow-out of small (3 mm SH) seed or forgo nursery grow-out by purchasing more costly larger seed (i.e., already 25 mm SH), separate sets of analyses were conducted with versus without an on-site nursery phase. The nursery phase can be conducted in shore-based upwellers or in field cages attached to racks in the shallow subtidal (<1 m below mean low water [MLW]) on submerged land leased from the state of North Carolina. For analytic results reported in this paper, all estimates that include on-site nursery grow-out are based on the latter alternative because the bottom racks that are used for grow-out can also be used for the nursery phase at no additional cost and the use of an upweller system requires waterfront property in addition to the bottom lease. Oyster growers that have access to flowing seawater might consider setting up an upweller system, especially if their bottom lease is not easily accessible or is susceptible to pilferage or storm damage. This difference in cost largely reflects the reduced cost of materials associated with nursery in the field (Table 1). During the nursery phase, 3-mm seed oysters are purchased and stocked in 2-mm mesh ADPI, Inc. bags (dimensions: 90 × 40 × 11 cm) at a density of 10,000/bag. Bags are then attached to 13-mm d. PVC frames reinforced with 12-mm d. steel bars that hold up to five bags each. In addition to anchoring the bags, frames elevate oysters 15 cm up into the water column to avoid benthic predators and to enhance food delivery through exposure to increased off-bottom flows (Grabowski et al. 2004). Bags are cleaned manually with wire brushes after every 2 wk to reduce negative effects of bag fouling on growth and survivorship. To facilitate growth during the nursery phase, oysters are graded by size and transferred after 1 mo to 9-mm mesh ADPI, Inc. bags (1,000 oysters/bag; bag dimensions: 90 × 40 × 11 cm), and bags are put back onto the racks (5 bags/rack). Oysters are cleaned again after another 2 wk before completing the nursery phase in an estimated 6 wk. Mortality during the nursery phase was estimated at 2% (Bishop & Peterson 2005a).

The third culture phase also involves field grow-out on shallow (<1 m below MLW) subtidal bottom using the rack-and-cage set-up. Use of the same racks for both phases of production increases the efficiency of the operation by reducing material and labor costs. Efficient use of bottom is also critical to maximizing the profitability of the culture operation given the expense of obtaining a bottom lease (one-time cost of $2,000 per acre). After the nursery phase is complete, grow-out is initiated by grading oysters by size and transferring them to 16-mm mesh bags at 150 per bag (5 bags per rack; bag dimensions 90 × 40 × 11 cm). Oyster grow-out requires an additional 4–9 mo, depending on salinity and season (Table 1). Culturing 500,000 oysters requires purchase of 3333 (500,000 oysters/150 oysters per bag) 16-mm bags and construction of 667 (3,333 bags/5 bags per rack) racks to complete this final phase of culture, and inclusion of a nursery phase on-site would require an additional 50 2-mm and 500 9-mm bags. The proposed operation requires acquisition of a 2.8-acre lease to complete oyster grow-out.

Salinity regimen and season of grow-out strongly influence oyster growth and survivorship, and subsequently may dictate whether culture operations are profitable and to what degree. These factors also affect relative infestation by *Polydora*-induced mud blisters (Bishop & Peterson 2005a), which can impact the type of market (i.e., half-shell vs. shucking) and thereby the price that a cultured oyster commands. Consequently, we conducted separate analyses using *C. ariakensis* survivorship, growth, and *Polydora* spp. infestation data from intermediate (10‰ to 25‰) versus high (>25‰) salinity waters in North Carolina during spring, summer, and winter initiation to determine how the profitability of oyster culture varies with all possible combinations of salinity regimen and grow-out season (Table 1). These two salinity regimes were chosen to reflect where culture is most feasible given that previous trials have demonstrated extremely poor oyster growth at low (<10) salinities (Grabowski et al. 2004, Bishop & Peterson 2005a). Unweighted averages of survivorship, growth, and *Polydora* infestation rates (i.e., % of oysters with >25% mud-blister cover) were calculated using data from replicate sites and/or years for each salinity regimen and season in which culture was initiated (Table 1).

Because juvenile (<25 mm SH) oysters can suffer catastrophic warm-season mortality from *Bonamia* sp. when raised in upwellers or the field in Bogue Sound at high salinities (Burreson et al. 2004), culture of oysters at this and other high-salinity sites may require subleasing bottom at an intermediate-salinity site to conduct the nursery phase of oyster production. This recent parasitic invader from Australia-New Zealand, which was originally detected in the Newport River in Bogue Sound has now been found in high-salinity waters near Wrightsville (Carnegie, unpub. data), suggesting that it could potentially spread throughout high-salinity habitats along the North Carolina coast. In our analyses we assume that summer culture operations at high salinities anywhere in the state will use an

TABLE 1.

Oyster survivorship (unweighted average of 3–5 replicated sites), time required for grow-out, and % of oysters with ≥25% of external shell covered with *Polydora* spp. blisters for culture initiated in the spring, summer, and winter at intermediate (10‰ to 25‰) versus high (>25‰) salinities (Grabowski et al. 2004, Bishop & Peterson 2005a).

Season of Initiation[1]	Salinity Regimen	% Survivorship	Grow-out Time (months)[2]	% of Oysters with >25% Mud Blister Coverage	Number of Replicate Sites[3]
Spring & Summer	High (>25‰)	56.2	4	35.3	5
	Intermediate (10‰ to 25‰)	75.4	7	61.6	5
Winter	High	90.0	6	0.1	3
	Intermediate	94.0	9	0.1	3

[1] Spring: the nursery phase begins in April and grow-out on June 1; summer: the nursery phase starts in June and grow-out on August 1; and winter: the nursery phase begins in September and grow-out commences on November 1. Previous growout data from the summer and fall were pooled and used for operations initiated in the spring and summer.

[2] Oysters are raised from 25 mm to 75 mm SH during grow-out.

[3] Location of replicate sites throughout coastal North Carolina used to calculate % survivorship during grow-out, grow-out time, and % of oysters covered with greater than 25% mud blister coverage. Culture initiated in the spring or summer at high salinities: Chadwick Bay (2001), Newport River (2001 and 2004), Topsail (2001), and Waters Bay (2001). Culture initiated in the spring or summer at intermediate salinities: Manteo (2004), Swan Quarter (2001 and 2004), Bay River (2001), and Wanchese (2001). Culture initiated in the winter at high salinities: Chadwick Bay (1999), Hoop Pole Creek (2004), and Bogue Sound (2004). Culture initiated in the winter at intermediate salinities: Manteo (2004), Swan Quarter site 1 (2004), and Swan Quarter site 2 (2004). See Grabowski et al. (2004) and Bishop and Peterson (2005a) for exact locations and physical parameters of each site.

intermediate-salinity site for nursery grow-out to avoid the risk of high *Bonamia*-induced mortality rates during the nursery phase. We also analyzed grow-out during a third season of initiation of field culture, spring, in which the sublease of bottom is avoided by completing the nursery stage by the beginning of June, prior to the onset of warmer water temperatures. Because the timing of the spring and summer operations is broadly overlapping; survivorship, growth, and mud-blister data from the summer were also used to calculate the profitability of an operation beginning in the spring. However, the costs associated with beginning the nursery phase in the spring versus the summer differ. This additional scenario is provided to determine if the added seed costs from beginning the nursery phase in the spring, well before hatcheries now typically provide seed outweigh the added costs of subleasing a midsalinity site during the summer to avoid *Bonamia*-induced mortality.

Triploid *C. ariakensis* seed (2–6 mm SH) is currently produced by the Virginia Institute of Marine Sciences and only for scientific research. Because commercial production of triploid seed is not currently underway, we estimated seed costs in the summer and the winter at twice the present-dollar cost of diploid *C. virginica* (based on S. K. Allen, pers. comm.), or $0.021 per 3 mm or $0.064 per 25 mm *C. ariakensis* seed in the summer and winter (Table 2). In all scenarios, culture operations include purchase of 500,000 seed oysters, so that operations including an on-site nursery phase ultimately planted slightly fewer oysters for grow-out than those that purchased larger seed. Large-scale production of triploid *C. ariakensis* eventually could result in a lower, more favorable seed price for growers. Producing seed for initiation of oyster seed planting in spring would require hatchery facilities to induce fertilization in late winter/early spring, which is just prior to the typical inception of spawning in oyster hatcheries for growers in the SE region. Colder water temperatures and the impacts of relative food deprivation in the spring would require greater costs to condition brood stock for spring spawning. An additional 50% was therefore added to the cost of seed of each size to estimate the cost of producing seed for initiation of outplanting in the field in the nursery phase in spring (Table 2).

Financial Operation

Several key assumptions regarding financial aspects of the culture operation influence estimates of profitability. No price data exist for *C. ariakensis* in North Carolina because there is no market for a hypothetical product. Thus, the oyster prices that growers would receive are based on estimates of what the wholesaler would pay the producer of cultured diploid *C. virginica* oysters. Cultured oysters typically end up in one of two markets: a more valuable half-shell market for raw and steamed consumption, or a shucked market. Cultured diploid *C. virginica* sell for $0.30/oyster on the half-shell (J. Swartzenberg, pers. comm.). In this study, the wholesale price of half-shell *C. ariakensis* is estimated at $0.25 to account for the fact that *C. ariakensis* is judged by consumers in taste trials to be slightly less palatable than *C. virginica* when eaten raw (Grabowski et al., 2003). We estimate the price for shucked *C. ariakensis* oysters at the native oyster price of $22 per diploid *C. virginica* bushel (North Carolina Department of Marine Fisheries, unpublished data). At 350 (75–85 mm SH) triploid *C. ariakensis* oysters per bushel (Summerson, unpub. data), the individual price per shucked *C. ariakensis* is $0.063.

An average annual budget was estimated with 0% financed on borrowed capital. Capital assets were depreciated using straight-line depreciation to calculate taxes, but depreciation value estimates were not included in the cash flow *per se*. Capital asset purchases, variable labor and materials costs, and overhead expenses were inflated at a 3% annual rate; whereas oyster prices remained constant throughout the study per methods in Adams and Blokland (1998). All future dollars were discounted at a rate of 9% to calculate the net present value (i.e., the opportunity cost of capital) of the operation. In addition to initial setup, hired labor is required to plant oysters in the field, periodically wash fouling and mud off cages, and harvest and sell oysters. Laborers are self-used individuals (i.e., this is a tax-inclusive rate) and are paid at an hourly rate of $10. From conversing with several commercial oyster growers, we estimated their annual repair and maintenance costs at 2% of the purchase cost of rack and cage equipment and 10% for the skiff, skiff motor, truck, and trailer. Federal and state income taxes and self-employment taxes were calculated for a sole proprietorship using the 2004 federal IRS and North Carolina tax rates. We did not amortize capital costs after five years because we are assessing the first five years of a potentially longer project venture.

For the annual enterprise budget, we calculated the net return to owner in nominal dollar values by subtracting the capital costs, production costs, and taxes from total revenues.

TABLE 2.

The cost of 3-mm and 25-mm (SH) seed for triploid *Crassostrea ariakensis* oyster culture commenced in spring, summer and winter. Seed prices were estimated by doubling existing prices for diploid *Crassostrea virginica* seed to account for added costs associated with producing triploid oysters (S. Allen, pers. comm.). An additional 50% was added to the cost of seed provided in spring to account for the difficulty in producing viable seed prior to the onset of the traditional hatchery season (May to August).

Season of Initiation	Spawned	Purchase Size	Purchase Date	Seed Cost ($/1,000 seed)	Grow-out Stage Begins
Spring	March	3 mm	April	21	1-Jun
		25 mm	Late May	96	1-Jun
Summer	May	3 mm	June	14	1-Aug
		25 mm	Late July	64	1-Aug
Winter	August	3 mm	September	14	1-Nov
		25 mm	Late October	64	1-Nov

Furthermore, we calculated the percent return on investment by dividing the revenues by the sum of these three groups of costs. We adjusted these two measures of economic performance to account for taxes using the 2004 tax codes to depict more accurately the profitability of culturing triploid *C. ariakensis*. However, these estimates will need periodic adjustment to account for future modifications in the United States and state tax codes. For the sake of ease of accounting, we calculated the return on the investment annually. Rather than initiating each subsequent oyster crop directly after completing grow-out, oyster crops are initiated seasonally on an annual cycle similar to agriculture. We also estimated that revenues are produced at the end of each 12-mo period. However, triploid *C. ariakensis* nursery phase and grow-out can be completed in 6–11 mo. Our estimates of return on investment are therefore conservative, and growers may want to consider selecting a salinity regimen and season of initiation that promote faster growth if they would prefer a longer off season and more rapid return on investment and production costs.

RESULTS

Initial Investment and Production Costs

Initial investment costs range from ~$96,000–99,000 in year 1 and then decline to near zero in years two and three because most equipment used in the operation has a life span of at least three years (Table 3; initial investment costs for the most profitable scenario, beginning culture operations in the winter at high salinity, are provided in Table 4). In year 4, purchase of a new skiff motor increases capita asset expenses to ~$7,000, and replacing bags raises capital expenses of the operation to ~$35,000 in year five regardless of where or when the operation is conducted. Initial investment costs vary only slightly as a function of whether the nursery phase is conducted on-site or if larger seed is purchased, the latter alternative only slightly reducing the initial investment cost. A summer culture operation at high salinities with an on-site nursery phase would require subleasing bottom at an intermediate-salinity site and thus necessitates the highest initial investment at $99,929. In general, purchase of rack materials is the largest contribution to initial investment at $30,000 for 667 PVC racks (expected lifespan of ~10 y), which accounts for ~30% of the equipment costs in year 1. Other major equipment investments include 550 nursery and 3,333 grow-out bags, just over $17,000 in labor to construct racks and bags, a 6-m skiff with a 60 hp outboard motor and trailer, a pickup truck, and a bottom lease. Labor costs to assemble equipment are considered a capital expense because these expenses are fixed costs associated with purchase of equipment rather than production costs. Some operations may already have a skiff or truck, but we assume that this operation would require these equipment investments or existing equipment would be depreciated and replaced given the intensive (i.e., >100 boat days used per year) nature of the culture operation. We assume that the potential grower owns land that is available for a shed and cold storage unit. *C. ariakensis* production without an on-site nursery phase would require slightly less (~$2,500–3,000 in years 1 and 5) initial capital investment for purchase and construction of nursery bags. However, this and additional cost savings in production costs (i.e., ~$1,500 in labor costs to conduct nursery phase) are outweighed by $25,000 (summer and winter initiations) to $37,500 (spring initiation) in higher variable (i.e., seed) costs.

In contrast to initial investment costs, production costs varied substantially as a function of each culture scenario (Table 3; production costs associated with beginning culture operations in the winter at high salinity are provided in Table 5). Purchase of larger (25-mm) seed to avoid need for a nursery operation increased production costs by 650% per year regardless of where or when the operation is conducted, and far exceeded the reductions in initial investment costs associated with avoiding on-site nursery operation. Seed costs accounted for 15% to 25% of the production costs of an operation with on-site nursery as compared with 45% to 61% of costs without a nursery phase. The cost of labor accounted for 47% to 60% of production costs for operations that include a nursery phase and 24% to 38% without. The additional time required to complete grow-out at intermediate-salinity sites increased

TABLE 3.

Estimated investment and production costs associated with *Crassostrea ariakensis* culture in North Carolina initiated in each of 3 seasons, at 2 salinity regimes, and with 3 mm SH) versus without (25 mm SH) an on-site nursery phase during the first five years of the operation. See Tables 4 (investment costs) and 5 (production costs) for examples of how these costs were quantified.

Season of Initiation	Initial Seed Size	Salinity Regimen	Investment Costs					Production Costs				
			Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5
Spring	3 mm	High (>25‰)	$99,179	$0	$265	$6,644	$35,311	$42,385	$43,657	$44,966	$46,315	$47,705
		Intermediate (10‰ to 25‰)	99,179	0	265	6,644	35,311	47,788	49,222	50,699	52,220	53,786
	25 mm	High	96,659	0	265	6,644	32,475	78,308	80,658	83,077	85,570	88,137
		Intermediate	96,659	0	265	6,644	32,475	83,712	86,223	88,810	91,474	94,218
Summer	3 mm	High	99,929	773	1,061	7,463	36,155	38,885	40,052	41,253	42,491	43,766
		Intermediate	99,179	0	265	6,644	35,311	44,288	45,617	46,985	48,395	49,847
	25 mm	High	96,659	0	265	6,644	32,475	62,308	64,178	66,103	68,086	70,129
		Intermediate	96,659	0	265	6,644	32,475	67,712	69,743	71,835	73,990	76,210
Winter	3 mm	High	99,179	0	265	6,644	35,311	42,552	43,829	45,144	46,498	47,893
		Intermediate	99,179	0	265	6,644	35,311	47,955	49,394	50,876	52,402	53,974
	25 mm	High	96,659	0	265	6,644	32,475	65,911	67,888	69,924	72,022	74,183
		Intermediate	96,659	0	265	6,644	32,475	71,314	73,453	75,657	77,926	80,264

TABLE 4.

An example of initial investment and capital asset requirements for small-scale commercial culture of *Crassostrea ariakensis* in North Carolina. Estimates below involve initiation of nursery phase on-site in winter at high salinities. Labor costs for equipment construction (i.e., bags and racks) are shaded, and capital asset costs are inflated at 3% per year.

		Materials		Labor				YEAR				
		Unit Price ($)	**Number**	**Acquisition (total hr)**	**Construct (hr/item)**	**Total Construction Time (hr)**	**Lifespan**	**1**	**2**	**3**	**4**	**5**
Nursery Phase												
Field nursery	Mesh size											
Bags w/clips[1]	2 mm	3.57	50	0.17	0.10	5.17	4	$178.73				$201.17
	9 mm	3.57	500	0.17	0.10	50.17	4	1,787.34				2,011.67
Labor		$10/h			Total Time:	55.33		553.33				622.78
Grow-out Phase												
Miscellaneous[2]		500.00	1				5	500.00				
Bags w/clips	16 mm	3.57	3,333	0.17	0.10	333.50	4	11,915.60				13,411.11
PVC racks		45.00	667	2.00	2.00	1335.33	10	30,000.00				
Labor		$10/h			Total Time:	1668.83		16,688.33				18,782.87
Equipment			1									
Skiff		10,000.00	1				10	10,000.00				
Motor		6,000.00	1				3	6,000.00			6,556.36	
Trailer		2,000.00	1				5	2,000.00				
Pick-up truck		10,000.00	1				5	10,000.00				
Wet suit or waders		250.00	2				2	500.00		265.23		281.38
Cooling unit & shed		3,000.00	1				10	3,000.00				
	# of acres	Cost per acre										
Bottom lease	2.78	2,000.00	1				>10	5,555.56				
Labor Investment												
Site/equipment selection		10.00		50.00				500.00			87.42	
Total Investment								**$99,178.90**	**$0.00**	**$265.23**	**$6,643.78**	**$35,310.97**

[1] Oyster stocking densities: 10,000/bag in 2-mm bags, 1,000/bag in 9-mm bags, and 150/bag in grow-out (16-mm) bags.

[2] Miscellaneous supplies include rope, cable ties, personalized sales labels, baskets, gloves, accounting materials, etc.

TABLE 5.

An example of production costs for commercial grow-out of *Crassostrea ariakensis* in North Carolina. Estimates below involve grow-out during winter at high salinities after on-site nursery production. Labor costs are shaded, and future production costs are inflated at 3% per year.

	Materials			Labor					Year				
	Unit Price ($)		**Number**	**Unit Time[1] (hr/unit)**	**Periods**	**Trips (# days/period)**	**Transport Time[1] (hr/trip)**	**TOTAL[1] (hr)**	**1**	**2**	**3**	**4**	**5**
	$/seed		# seed/yr										
Seed	$0.014		500,000						$7,000.00	$7,210.00	$7,426.30	$7,649.09	$7,878.56
Supplies/expendables (gloves, boxes, label tags, etc.)									2,000.00	2,060.00	2,121.80	2,185.45	2,251.02
Fuel/oil/electricity	Monthly fee		# months										
Skiff/truck	$100.00		8						800.00	824.00	848.72	874.18	900.41
Cooling unit	$75.00		6						450.00	463.50	477.41	491.73	506.48
Maintenance	Unit price	Annual rate	# units	Hr/item									
Skiff/truck/cooling unit	$28,000.00	10%	1	25.00				25	2,800.00	2,884.00	2,970.52	3,059.64	3,151.42
Bags	$3.57	2%	66.67	0.10				7	238.31	245.46	252.83	260.41	268.22
Frames	$45.00	2%	13.33	2.00				27	600.00	618.00	636.54	655.64	675.31
Labor	$10/h						Total Time:	58	583.33	600.83	618.86	637.42	656.55
Wages				Per trip									
Nursery phase			# racks	Hr/rack									
Plant			8	0.50	1	1	1.50	6					
Clean 2-mm bags			8	0.25	2	1	0.33	5					
Mid transfer			83	1.00	1	5	1.50	91					
Clean 9-mm bags			83	0.25	2	1	0.33	43					
Labor	$10/h						Total Time:	144	1,441.81	1,485.06	1,529.61	1,575.50	1,622.76
				Per trip									
Grow-out phase			# racks	Hr/rack									
Plant seed			667	1.00	1	42	1.50	729					
Clean bags			667	0.25	6	10	0.33	1021					
Harvest oysters			667	0.25	1	10	0.50	172					
Weigh and bag oysters			667	0.33	1	14	0.00	222					
Labor	$10/h						Total Time:	2,144	21,438.89	22,082.06	22,744.52	23,426.85	24,129.66
	$/oyster	# oysters											
Disease testing[2]	$20.00	60							1,200.00	1,236.00	1,273.00	1,311.27	1,350.61
Reversion testing	$3.00	1,000							3,000.00	3,090.00	3,182.70	3,278.18	3,376.53
Overhead expenses	annual												
Insurance/bookkeeping/ accounting	$1,000.00								1,000.00	1,030.00	1,060.90	1,092.73	1,125.51
Total									**$42,552.34**	**$43,828.91**	**$45,143.78**	**$46,498.09**	**$47,893.03**

[1] Total hours for equipment (i.e., skiff/truck/cooling unit, bags, and frames) maintenance are the number of units for each type of equipment multiplied by the hours of maintenance required per unit item. Total hours for wages, which are separated into the nursery and grow-out phases, are the sum of the transport time (i.e., time spent loading and unloading materials as well as traveling to and from lease site) and the amount of time per rack (i.e., time spent deploying rack, fastening bags to rack, cleaning bags, etc.) per event multiplied by the number of racks and number of events (i.e., the number of time periods each activity is conducted).

[2] The "mid transfer" during the nursery phase and the "plant seed" during the growout stage also include time to size-grade oysters.

[3] In North Carolina, disease (*Perkinsus marinus* and *Haplosporidium nelsoni*) testing is required for seed purchased from an out of state hatchery. Importation of alien oyster seed also requires ploidy testing, which is included in the quoted hatchery price. Funds are budgeted for reversion testing conducted during grow-out to insure that oysters are still triploid.

annual production costs (i.e., additional visits to clean cages) for operations with a nursery phase by 13% to 14% and those without by 7% to 9%. Additional labor associated with longer grow-out periods over the winter increased operating costs by 5% to 9% in comparison with operations during the summer. Finally, higher seed costs associated initiating the operation in spring increased production costs by ~7% to 8% (with onsite nursery) and 19% to 20% (without onsite nursery) in comparison with operations initiated in the summer.

Cash Flow Statement and Annual Enterprise Budget

In general, the present value of the cash flow assessment projects the profitability of the venture over the first five years of the operation, and indicates if and when the operation breaks even during this time period. Whether project operations were profitable in the first five years of operation was influenced most heavily by the season in which culture was initiated (Table 6; see Table 7 for an example cash flow for an operation beginning in the winter at a high-salinity site). Operations initiated in winter generally were profitable within the first 3–4 y, and netted up to a cumulative ~\$124,000 (or ~\$70,000 net present value [NPV]) in the first five years of operation. In contrast, operations conducted in the warmer months failed to recoup investment and operating costs and ended up losing from \$99,000 to \$327,000 (or \$102,000 to \$295,000 NPV) over the first five years of production. When initiating the operation in the winter, inclusion of a nursery phase increased the profitability 4-fold at high salinities and from breaking even to a profit of \$56,000 at intermediate salinities (Table 6). In both of the other two seasons, purchase of larger seed increased monetary losses accumulated over the 5 y operation by a factor of 2–3. Finally, salinity regimen affected the profitability of the culture operation in the winter with high-salinity sites generally \$13,000–14,000 more profitable than intermediate-salinity sites (Table 6).

The annual enterprise budget is the steady-state operational budget, and includes the percent return on the investment, the break-even price, and the break-even survivorship rate (see Table 8 for an example annual enterprise budget for an operation initiated in the winter at a high-salinity site). Once again, only operations initiated in winter were profitable, with annual profits ranging on average from ~\$12,000 to ~\$25,000, or an 11% to 29% annual return on the investment (Table 9). The salinity regimen had little effect on the net return on the investment for operations initiated in the winter; however, reduced operating expenses at the high-salinity site associated with faster oyster growth and lower labor costs for cage cleaning resulted in slightly greater percent return on the investment. Inclusion of the nursery phase on-site generally increased the profitability of winter start-ups by ~60% over operations that purchased larger seed. Operations initiated in the spring and summer generally averaged a net loss of between \$20,000 and \$63,000 per year in nominal dollars, or a –28% to –56% return on investment. Sixty-five percent of the loss at intermediate and 37% at high salinities is attributable to *Polydora* fouling, whereas mortality from crabs and other sources accounted for 35% of the loss at intermediate and 63% at high salinities. Operations initiated in the warmer months endured greater losses at intermediate than at high salinities primarily because grow-out was longer and consequently more costly at intermediate-salinity sites.

The break-even price and the break-even survivorship rate also varied as a function of the timing and location of the culture operation (Table 9). The break-even price was highest when culture was initiated in the spring at high-salinity sites when survivorship during grow-out was low (56%) and seed costs were elevated. However, the break-even survivorship rate, which was adjusted to account for the proportion of oysters covered (>25%) with mud blisters, was highest during the warmer months at the intermediate-salinity sites where *Polydora* spp. infestation peaked at 62%. When culture was initiated during the colder months, the break-even price was slightly greater at high-salinity sites because survivorship was slightly less than at intermediate salinities. Yet the break-even survivorship rate was slightly lower at high salinities because of lower

TABLE 6.

Estimated ending cash balance (net present value) at the end of each of the first five years of operation for *Crassostrea ariakensis* culture in North Carolina initiated in each of three seasons, at two salinity regimes, and with versus without an on-site nursery phase. Capital investments were not financed for the projected operations (i.e., owner-operator is using his or her own money and there is no computation for interest foregone). See (Table 7 for a more detailed example of a cash flow for the operation.

Season of Initiation	Initial Seed Size	Salinity Regimen	Ending Cash Balance (NPV) Yr 1	Yr 2	Yr 3	Yr 4	Yr 5
Spring	3 mm	High (>25‰)	(\$93,085)	(\$88,738)	(\$86,004)	(\$89,464)	(\$113,930)
		Intermediate (10–25‰)	(100,329)	(102,699)	(106,340)	(115,780)	(145,859)
	25 mm	High	(124,769)	(152,713)	(180,610)	(213,053)	(262,936)
		Intermediate	(132,079)	(166,878)	(201,204)	(239,678)	(295,219)
Summer	3 mm	High	(90,335)	(83,545)	(78,495)	(79,634)	(101,908)
		Intermediate	(96,829)	(95,892)	(96,408)	(102,895)	(130,183)
	25 mm	High	(108,769)	(121,594)	(135,204)	(154,146)	(191,271)
		Intermediate	(116,079)	(135,758)	(155,797)	(180,771)	(223,555)
Winter	3 mm	High	(37,701)	(1,283)	31,563	58,672	70,669
		Intermediate	(40,876)	(7,188)	23,074	47,744	57,302
	25 mm	High	(54,850)	(28,264)	(4,994)	12,339	13,080
		Intermediate	(57,946)	(34,125)	(13,481)	1,361	(561)

TABLE 7.

An example of annual cash flow for *Crassostrea ariakensis* production with nursery operation on-site in high-salinity waters initiated during the winter in North Carolina. Estimates below include on-site nursery production after purchase of 3-mm seed. Total cash receipts are derived from sale of oysters on the half-shell (i.e., to restaurants and dealers) and shucked markets. Expenses are italicized, and capital investments were not financed for the projected operation. The annual cash position is the profits (or losses) derived during a particular year, whereas the ending cash balance is for the lifespan of the operation. The ending cash balance was adjusted by an annual discount rate of 9% to quantify the net present value of the project.

	Year				
	1	2	3	4	5
Beginning cash balance	$0				
Total cash receipts	$110,214	$110,214	$110,214	$110,214	$110,214
Total cash outflow					
Production costs	42,552	43,829	45,144	46,498	47,893
Capital assed costs	99,179	0	265	6,644	35,311
Taxes (federal and state)	0	20,505	19,598	15,781	3,891
Total	141,731	64,334	65,007	68,923	87,095
Annual cash position	(31,518)	45,879	45,207	41,290	23,119
Ending cash balance	($31,518)	$14,362	$59,569	$100,859	$123,978
Net present value (NPV)	($37,701)	($1,283)	$31,563	$58,672	$70,669

production costs (i.e., shorter grow-out time) than at intermediate salinities. Finally, using larger seed instead of an on-site nursery generally increased the cost per oyster and the break-even survivorship rate by ~10% to 30% for winter and ~27% to 47% for warmer-season initiations.

Sensitivity Analyses

Sensitivity analyses were conducted for the most profitable scenario, a winter initiation at high salinities with the nursery phase conducted on-site. The operation was quite robust to variation in seed price, with a ~50% increase in seed price reducing the percent return on the investment by only 2.8% because seed costs were only a small proportion of total investment and production costs (Table 10). The size of the operation had a stronger affect on the profitability of the operation, with larger operations resulting in a greater return on the investment. Economies of scale occurred because of fixed capital costs such as the costs of a truck, skiff, trailer, and cooling shed that are independent of the number of oysters planted (i.e., fixed costs are being amortized over a larger output). However, even the smallest projected operation (250,000 oysters) resulted in a 9.2% return on the investment. The largest projected operation involves culturing 2 million oysters per year, which increased profitability by 12.4% over the base operation of 500,000 oysters per year because of economies of scale. The operation was also somewhat robust to market price variability, with the venture turning a slight profit even at the lowest modeled price of $0.15 per oyster. Yet increasing the price from $0.25 to $0.35 did increase the percent return on the investment from 29.0% to 45.0%. The culture operation was highly sensitive to mud-blister infestation: sensitivity analyses demonstrated that the return on the investment ranged from a 29.0% (no infestation) profit to a 62.5% loss (100% oysters with at least 25% mud blister cover). A mud-blister infestation rate of 43.9% completely negated profits. Only the lowest oyster survivorship rate (50%) resulted in a net loss on the investment, whereas each 10% increment increase in survivorship generally resulted in a ~10% gain in the percent return on the investment.

Investigation of the effects of mud-blister infestation in the spring and summer revealed that resolving this impediment to growout would result in some but not all scenarios becoming profitable. In the summer, a mud-blister infestation rate of 19.5% at intermediate salinities negated profits for operations with a nursery phase. Operations initiated in the summer at high salinities without mud-blister infestations still recorded a 7.1% loss. Mud-blister infestation rates of 14.5% completely negated profits for spring-initiated operations with a nursery phase at intermediate salinities, whereas operations initiated in the spring at high salinities without mud-blister infestation lost 10.2% return on the investment. Operations initiated in the spring or the summer that purchased larger seed to avoid the nursery phase resulted in ~8% to 40% losses in the complete absence of mud-blister infestation.

DISCUSSION

Introduction of a nonnative species of oyster to the east coast of the USA should be contingent on perceived benefits outweighing estimated costs (ICES 1995, National Research Council 2003, Simberloff 2005). Although many of the benefits of oysters derive from their provision of services such as habitat, filtration of the water and stabilization of shorelines, perhaps the politically most important is the anticipated social and economic boost generated by a wild fishery or aquaculture industry. Previous studies have demonstrated that triploid *C. ariakensis* survivorship and growth rates are relatively high in comparison with the native oyster (Calvo et al. 2001, Grabowski et al., 2004, Bishop & Peterson 2005a), implying that this species could be a viable candidate for culture production. Yet *Polydora* spp. infestation, which is predominately a problem during warmer months (Bishop & Peterson 2005a), poses a serious threat to the success of culture operations, because profitable oyster culture is contingent on producing and marketing oysters for the more valuable half-shell market. This study demonstrates that culture of triploid *C. ariakensis* oysters could be profitable but emphasizes the importance of salinity and especially seasonal timing of culture operations to its success. We

TABLE 8.

An example of the average annual enterprise budget for commercial culture of *Crassostrea ariakensis* in North Carolina initiated during the winter in high-salinity waters. Estimates below include on-site nursery production after purchase of 3-mm seed.

		Units	Price/Unit	Total Value/Cost
Revenues	Survival			
nursery phase mortality =2%	98.0%			
C. ariakensis	88.2%	441,084		
	Proportion			
Half-shell market	99.9%	440,777	$0.25	$110,194
Shucked market (mud blisters >25%)	0.1%	306	$0.06	$19
Variable Costs				
Seed oysters		500,000	$0.01	$7,000
Supplies				$2,124
Fuel/oil/electricity				
Skiff/truck				$849
Cooling unit				$485
Maintenance				
Skiff/truck/cooling unit				$2,973
Bags				$257
Racks				$646
Wages (maintenance only)			$10/h	$628
Labor				
Purchase seed & nursery phase			$10/h	$1,531
Grow-out phase			$10/h	$22,764
Disease & reversion testing				$4,460
Overhead expenses				$1,062
Operating debt interest				$0
Total variable costs				$44,779
Fixed Costs				
Overhead expenses				
Lease				$1,111
Insurance/bookkeeping/accounting				$1,062
Interest on long-term debt interest				$0
Capital assets				$14,708
Depreciation				$12,370
Total fixed costs				$29,251
Total Expenditures (excluding tax)				$74,030
TAX				
Self employment				$5,536
Income				$5,894
Net return to owner (nominal value)[1]				$24,753
Percent return on investment (nominal value)				29%
Cost per oyster (break-even price)[2]				$0.19
Break-even survivorship rate[3]				
Half-shell market only				59%
Adjusted to include shucked oysters				59%

[1] Net return to the owner is the average annual profits (or losses) derived from the operation, and is calculated by subtracting expenses (including taxes) from total revenues, and the percent return on the investment is calculated by dividing the net return to the owner by the total expenses (including taxes).

[2] The cost per oyster or break-even price for the operation is calculated by dividing the total expenses (excluding taxes) by the total number of oysters harvested.

[3] The break-even survivorship rate for the operation, including both the nursery phase (if on-site) and grow-out, is calculated by dividing the total costs of the operation (excluding taxes) by the oyster price on the half-shell market (half-shell market only) and by the adjusted average price that accounts for the proportion of oysters that are infested by *Polydora* spp. and sold on the shucked market (adjusted to include both markets).

chose to use data from only North Carolina for our analyses rather than include data from further away that may not be representative of North Carolina's estuaries. Although initial inspection of the results of previous and ongoing studies on the biological performance of triploid *C. ariakensis* in the Chesapeake does not suggest major departures from our findings, analogous analyses should be used to determine the economic viability of its culture in coastal Maryland and Virginia.

Our results indicate that the timing of field operations is critical to the viability of an aquaculture industry based on *C. ariakensis*. Only operations initiated in the winter were profitable, whereas operations initiated in the spring and summer suffered financial losses regardless of salinity regimen. Although reducing survivorship rates during grow-out and increasing *Polydora* spp. infestation negatively affected culture operations at both intermediate and high salinities, the relative importance of these two

TABLE 9.

Estimated profitability of *Crassostrea ariakensis* culture in North Carolina in each of three seasons, at two salinity regimes, and with versus without an on-site nursery phase. See Table 8 for a more detailed example of the annual enterprise budget. All reported values are in nominal dollars (net return on investment and cost per oyster) or calculated from nominal dollar estimates (% return on investment and break even survivorship rates).

Season of Initiation	Initial Seed Size	Salinity Regimen	Net Return on Investment[1]	% Return on Investment	Cost per Oyster (Break-even Price)[2]	Break-even Survivorship[3]
Spring	3 mm	High (>25‰)	($23,023)	–31%	$0.27	80%
		Intermediate (10‰ to 25‰)	($29,622)	–37%	$0.21	118%
	25 mm	High	($56,722)	–52%	$0.39	118%
		Intermediate	($63,338)	–56%	$0.30	169%
Summer	3 mm	High	($19,523)	–28%	$0.25	76%
		Intermediate	($26,122)	–34%	$0.21	113%
	25 mm	High	($40,722)	–44%	$0.33	100%
		Intermediate	($47,338)	–48%	$0.26	146%
Winter	3 mm	High	$24,753	29%	$0.19	59%
		Intermediate	$24,173	27%	$0.17	64%
	25 mm	High	$12,247	12%	$0.21	77%
		Intermediate	$11,720	11%	$0.22	82%

[1] Net return on the investments is the average annual profits (or losses) derived from the operation, and is calculated by subtracting expenses (including taxes) from total revenues, and the percent return on the investment is calculated by dividing the net return on investment by the total expenses (including taxes).

[2] The cost per oyster or break-even price for the operation is calculated by dividing the total expenses (excluding taxes) by the total number of oysters harvested.

[3] The break-even survivorship rate for the operation is calculated by dividing the total costs of the operation (excluding taxes) by the adjusted average price that accounts for the proportion of oysters that are sold on the half-shell market ($0.25/oyster) versus oysters infested by mud blisters and sold on the shucked market ($0.06/oyster).

factors in contributing to economic failure differed with salinity regimen. At intermediate salinities, *Polydora* spp. infestation was the more important of the two factors. Infestation rates at intermediate salinities were even greater than the projected break-even rate for the most profitable scenario, winter initiation at high salinities (Table 10). At high salinities, poor survivorship during grow-out was the main contributor to poor economic performance during the warmer months. Even though Grabowski et al. (2004) found high variability in survivorship among sites during summer grow-out, survivorship at none of the four high-salinity sites surpassed the break-even survivorship rate of 71.4%. Bishop and Peterson (2005a) did demonstrate higher survivorship (87.9%) during summer at their only high-salinity site, but documented extremely high mud-blister infestation rates (90.0%) for oysters raised on racks at this site.

Our *Polydora* spp. infestation rates may be overestimated because experimental oysters used to provide information for spring and summer initiation scenarios, had actually been spawned in the previous summer and held in crowded conditions in field small-mesh nursery bags in intermediate salinity for up to 9 mo prior to the inception of grow-out (Grabowski et al., 2004, Bishop & Peterson 2005a). They thus experienced two summers of exposure to *Polydora* spp. settlement. Oysters in commercial operations would only experience one summer season of *Polydora* spp. infestation at most. Scientists and fishermen who experimentally culture *C. ariakensis* in the coastal regions of Maryland and Virginia have, however, also reported high mud-blister infestation rates (K. T. Paynter & R. B. Carnegie, personal communication), suggesting that mud blister infestation may indeed limit the profitability of summer culture of this oyster even when seed oysters can be provided during the spring of the year of initiation of grow-out.

During the winter, oyster culture was profitable in spite of slower oyster growth rates because survivorship during grow-out was high (90% to 94%) and *Polydora* spp. infestation negligible. Oyster culture was slightly more profitable at high salinities than at intermediate salinities, because the lower cost of a shorter grow-out phase at high salinities outweighed the additional revenue from greater survivorship at intermediate salinities. However, culturing oysters at either intermediate or high salinities resulted in a high return on the investment of ~33% to 35% provided that smaller seed was purchased and the nursery phase was conducted on-site. Culturists unwilling to incorporate the nursery phase into their production scheme would still be capable of recovering a more modest profit of 11% to 12% for operations initiated in the winter, and would avoid the potential risk of high seed mortality from predation during the nursery phase. Because growth is slower during the winter, culturists operating at intermediate-salinity sites should carefully plan the timing of their operation to complete grow-out and sales before the summer to avoid potential *Polydora* spp. infestation. Given that *Polydora* spp. infestation was highest at intermediate salinities and that profitability was extremely sensitive to *Polydora* spp. infestation rates, infestation could threaten the economic viability of *C. ariakensis* culture initiated in the winter at intermediate salinities if any of several factors intervened to retard growth.

The success of culture operations initiated in the winter is contingent on being able to sell oysters in April, May, and June when the traditional season is closed, which raises concerns over whether new markets would create enough demand for oysters during the spring. One grower in North Carolina is currently selling triploid *C. virginica* successfully in the spring (J. Swartzenberg, pers. comm.), suggesting that demand for a

TABLE 10.

Summary of single-variable sensitivity analyses on the profitability of *Crassostrea ariakensis* culture in North Carolina during the winter at high salinity. In particular, the effects of variation in seed price, the number of oysters planted, market price, *Polydora* spp. infestation, and survivorship rate during oyster culture on profitability were assessed. All reported values are in nominal dollars (net return on investment and cost per oyster) or calculated from nominal dollar estimates (% return on investment and break even survivorship rates).

Variable	Total Costs[1]	Net Return on Investment[2]	% Return on Investment	Cost per Oyster (Break-even Price)[3]	Break-even Survivorship[4]
Seed price					
$0.008	$83,798	$26,416	31.5%	$0.190	56.8%
$0.011	$84,589	$25,625	30.3%	$0.192	58.0%
$0.014	$85,461	$24,753	29.0%	$0.194	59.2%
$0.017	$86,401	$23,812	27.6%	$0.196	60.4%
$0.020	$87,342	$22,872	26.2%	$0.198	61.6%
No. oysters planted					
250,000	$50,442	$4,665	9.2%	$0.229	79.4%
500,000	$85,461	$24,753	29.0%	$0.194	59.2%
1,000,000	$162,883	$57,544	35.3%	$0.185	49.2%
2,000,000	$311,784	$129,071	41.4%	$0.177	44.1%
Market price (half-shell market)					
$0.15	$74,030	($7,895)	–10.7%	$0.168	98.7%
$0.20	$77,330	$10,845	14.0%	$0.175	74.0%
$0.25	$85,461	$24,753	29.0%	$0.194	59.2%
$0.30	$95,803	$36,449	38.0%	$0.217	49.4%
$0.35	$106,397	$47,894	45.0%	$0.241	42.3%
Mud blister infestation rate					
0%	$85,461	$24,753	29.0%	$0.194	59.2%
25%	$77,812	$11,823	15.2%	$0.176	72.9%
50%	$74,030	($5,032)	–6.8%	$0.168	94.7%
75%	$74,030	($25,669)	–34.7%	$0.168	135.0%
100%	$74,030	($46,305)	–62.5%	$0.168	235.6%
Survival rate					
50%	$74,030	($11,563)	–15.6%	$0.296	
60%	$74,173	$788	1.1%	$0.247	
70%	$77,104	$10,350	13.4%	$0.220	
80%	$81,632	$18,316	22.4%	$0.204	
90%	$86,433	$26,009	30.1%	$0.192	

[1] Total costs include all investment costs, operating expenses, and taxes.

[2] Net return on the investment is the average annual profits (or losses) derived from the operation, and is calculated by subtracting expenses (including taxes) from total revenues, and the percent return on the investment is calculated by dividing the net return on investment by the total expenses (including taxes).

[3] The cost per oyster or break-even price for the operation is calculated by dividing the total expenses (excluding taxes) by the total number of oysters harvested.

[4] The break-even survivorship rate for the operation is calculated by dividing the total costs of the operation (excluding taxes) by the oyster price on the half-shell market (half-shell market only) and by the adjusted average price that accounts for the proportion of oysters that are infested by *Polydora* spp. and sold on the steamer market (adjusted to include steamers only).

half-shell oyster in the spring and summer may already exist. But how stable the price may be to large increases in supply of cultured triploids is unclear, and should be investigated further prior to the inception of *C. ariakensis* introduction. Consumer surveys conducted by Bishop and Peterson (2005b) also confirmed that coastal residents of North Carolina would be willing to buy oysters in the spring, though commented that these oysters were more watery and slightly less desirable than oysters in the fall.

This work preceded development of biosecurity requirements that now dictate some precautions such as mesh under the footprint of racks to catch any seed oysters spilled out by an accident that breaks the integrity of the bag. Therefore, biosecurity costs are not included in these analyses. However, the cost of such mesh in present dollars is 0.12$ per square foot, and would cost ~$900 for a 3-acre lease with 500,000 oysters per year. Other expenses related to biosecurity would likely be added by regulators attempting to guard against unintended release of *C. ariakensis*.

Crassostrea ariakensis contains approximately twice as much meat as a similar-sized *C. virginica* (Grabowski et al. 2003). At the current legal size for *C. virginica* oysters of 75 mm (SH), consumers in taste trials raised concerns over whether *C. ariakensis* is too large to consume raw or steamed (C. Lewis, pers. comm.). Thus, development of a successful half-shell market for triploid may require marketing a smaller oyster (Bishop & Peterson 2005b), which would shorten grow-out times and reduce costs. The shelf-life of triploid *C. ariakensis* in cooling units is seemingly much shorter than

C. virginica because *C. ariakensis* oysters begin to gape 2–3 days after being harvested (Bishop, unpub. data), whereas the shelf-life of *C. virginica* is over two weeks. Even if oyster gaping is a natural phenomenon for *C. ariakensis* that does not render it unable to be consumed, current perception among oyster consumers and dealers (i.e., restaurants and seafood markets) of gaping *C. virginica* oysters as a health risk would pose a serious threat to *C. ariakensis*' marketability. An additional limitation is that shucking houses that have been given triploid *C. ariakensis* have noted that its thin shell results in splintering during shucking, although larger *C. ariakensis* do not suffer from this shell-splintering problem (D. Newman, Newman Seafoods, pers. comm.). Therefore, shucking houses would more than likely require triploid *C. virginica* oysters to be larger than the legal size for *C. virginica,* which should not pose a serious limitation given that *C. ariakensis* grows quickly.

If culture operations are initiated successfully and production of oysters throughout coastal North Carolina increases dramatically, it is unclear whether the demand for oysters can sustain the current market price (National Research Council 2003). Concerns have been raised in recent years about whether the demand for oysters has decreased significantly such that the currently reduced supply may still outstrip demand (Byrne 1996). Given the ecological risks associated with introducing a nonnative species even just for triploid culture (NRC 2003), the positive economic impact on coastal communities and especially commercial growers should be disproportionately large relative to the potential risks to justify introduction. It is possible that if North Carolina were to accomplish a goal of establishing several new culture operations around the state, local markets, and restaurants would be incapable of handling the surge in supply. Thus, one of the unintended economic consequences of establishing a nonnative cultured oyster fishery may be creating a surplus in oyster supply, which would probably depress the market price for oysters and negatively impact the profitability of *C. ariakensis* culture. The few local growers that are still producing the native oyster for consumption in the spring may also be adversely affected by this surge in supply.

For the purpose of this study, we compiled biological performance data from field trials on triploid *C. ariakensis* conducted at intermediate and high salinities during the summer and winter over the past five years. Because we averaged mortality, growth, and mud-blister infestation rates in our analyses, we produced discrete point estimates of the profitability of each culture scenario. For any given scenario, biological performance data used in the results were based on 3–5 replicate sites. Variability in survivorship (i.e., 17.7% to 87.9%) and mud blister infestation (0% to 90%) was greatest at high-salinity sites when growout was initiated in the summer, suggesting that our estimates for this scenario are potentially the least certain and that further grow-out trials would be most beneficial under these conditions.

Given that culture of *C. ariakensis* can be profitable, the projected value to the fishery (i.e., estimated profits per operation multiplied by the estimated number of new operations) and ancillary ecosystem benefits should now be quantified and weighed against the potential ecological and economic risks associated with introduction. Yet careful consideration should be given to whether diploid and triploid native oysters would serve as possible alternatives. Even though oyster culture of the native species requires more time to complete grow-out, it is already being conducted successfully in some regions of the United States (especially in the Gulf of Mexico and the northeast). Use of a triploid native oyster could enhance survivorship by reducing the duration of grow-out and consequent exposure to oyster diseases and *Polydora* infection. Triploid *C. virginica* has been successfully marketed in the spring on a limited basis already and reportedly is not watery (J. Swartzenberg, pers. comm.), suggesting that it may be a higher quality product than triploid *C. ariakensis*, which are watery in the spring. A more extensive triploid native oyster fishery would also open up markets during the summer when the traditional diploid oyster is less palatable because tissue quality is poor for reproductively capable oysters during the spawning season. Most importantly, use of the native oyster would circumvent the ecological and economic risks associated with introducing a nonnative species, such as the unintended consequences as well as the unforeseen local and regional impacts that often do not occur for years or even decades after the initial introduction (Carlton 1992, Simberloff 2005). Bioeconomic modeling of diploid and triploid *C. virginica* would greatly enhance our understanding of the degree to which these are viable options.

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