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Adding value to live, commercial size soft-shell clams (*Mya arenaria* L.) in Maine, USA: results from repeated, small-scale, field impoundment trials

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Abstract

The soft-shell clam (*Mya arenaria* L.) fishery in the state of Maine, USA, is worth \$5–10 million annually and is primarily based on the sale of live individuals. More than 80% of the catch is sold for the "steamer clam" market that is highly seasonal due to supply and demand. Prices paid to harvesters for live clams throughout the year increases by as much as 70% during a 4-month period between early spring and late summer. If clams harvested in the spring could be held until late summer, a value-added product could be developed in this fishery. From April to August 1996, at an intertidal and subtidal location in eastern Maine, I tested whether it was biologically feasible to impound commercially harvested clams (shell length = 44–75 mm) at densities between 720 and 850/m^2 using cages and nets (1.12 m^2) to protect animals from predators. Survival was 91.7% ($n = 12$) and 91.6% ($n = 6$) at the intertidal and subtidal site, respectively. There was no discernible shell growth during this period and there was no difference between initial and final clam weights. The methodology was transferred to commercial harvesters in two Maine communities: Wiscasset (1997 and 1998) and Perry (2000). Impounded clams ($\bar{x} = 21.8$ kg/cage; $n = 18$) lost, on average, 5 kg/cage in 1997 and 1998, whereas no significant net loss in wet weight occurred in cages deployed in 2000 ($\bar{x} = 23.2$ kg/cage; $n = 3$). Differing harvesting and handling methods of individual clammers, prior to impounding clams, likely explains the variation in weight lost during the impounding periods. The difference in price per live kilogram between the beginning of the impounding period and the August sale date resulted in an average gain of \$13.60/cage for clammers in 1997 and 1998 and \$57.73/cage in 2000. Simple culture techniques can be used to increase the value of the live harvest of soft-shell clams along the coast of Maine. Clam impoundments may be a way for communities that co-manage the public clam resource

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with the state's marine resource agency to generate funds to pay for traditional management schemes, as well as enhancement programs that employ hatchery-reared juveniles. In addition, an indirect benefit of clam impoundments might be to create spawner sanctuaries since animals are impounded during the time when gamete release occurs.

Keywords: Soft-shell clam; *Mya arenaria*; Impounding; Cages; Value-added; Maine

1. Introduction

In Maine, USA, soft-shell clams (*Mya arenaria* L.) have been harvested commercially by hand, year-round, from soft-bottom intertidal areas since the mid-1800s (Wallace, 1997). Historically, Maine's soft-shell clam fishery annually ranked second in economic importance behind only lobster (*Homarus americanus* Milne Edwards). In 2000, for example, approximately 1000 metric tons (mt) were landed in Maine, worth nearly \$10 million, ranking the clam fishery third in value of all commercial marine species behind lobsters and sea urchins, *Strongylocentrotus droebachiensis* (Müller) (DMR, 2000a). During the past 15 years, however, clam landings have steadily declined (Fig. 1), especially in eastern regions of the state, where, in the past, 45–65% of all clams in Maine are landed (Beal, 1994; Fegley et al., 1996). The clam fishery in Maine is a public one that is co-managed by coastal communities that cooperatively work with the state's marine resources department. The primary goal of all management schemes is to increase landings through limiting licenses, staggering area closures and openings, and improving water quality (Wallace, 1997). Attempts to enhance wild stocks with hatchery-reared juveniles of *M. arenaria* have been moderately successful, but these programs have occurred only in localized areas (Beal et al., 1995). To date, there has been no attempt by harvesters or others in Maine and elsewhere to increase the value of existing commercial stocks. Only a small percentage (< 15%) of the clam harvest becomes a value-added product and that occurs primarily during the summer months after clammers sell their catch to dealers/processors who separate the clam meats from the shells (shuck) for the fried clam and clam chowder markets (Clime and Townsend, 1993). Each year, a seasonal disparity occurs in the prices that clammers receive per live kilogram (kg). Because of this, the potential exists for harvesters, clam dealers/processors, or entrepreneurs to enhance the value of the live product through simple field culture techniques.

During a 4-month period between April–May and August–September, the price of live clams typically increases by > 70% (Fig. 2), and this disparity geographically varies along the coast, with the prices fluctuating more widely in the mid-coastal and southwestern regions (Fig. 3). That is, prices paid for clams harvested from intertidal flats during the spring range from \$1.65–\$1.95/live kg whereas prices for live clams in late August and early September range from \$2.80–\$4.00/live kg. These differences are due to a higher demand in the late summer for a live clam product, both within and outside the state of Maine (Clime and Townsend, 1993), combined with lower clam supplies as many clammers trade their clam hoes for rakes to harvest the seasonal blueberry (*Vaccinium angustifolia*) crop (Graham, 1989) while others enter the lobster fishery at the time of its peak harvest (Acheson and Steneck, 1997).

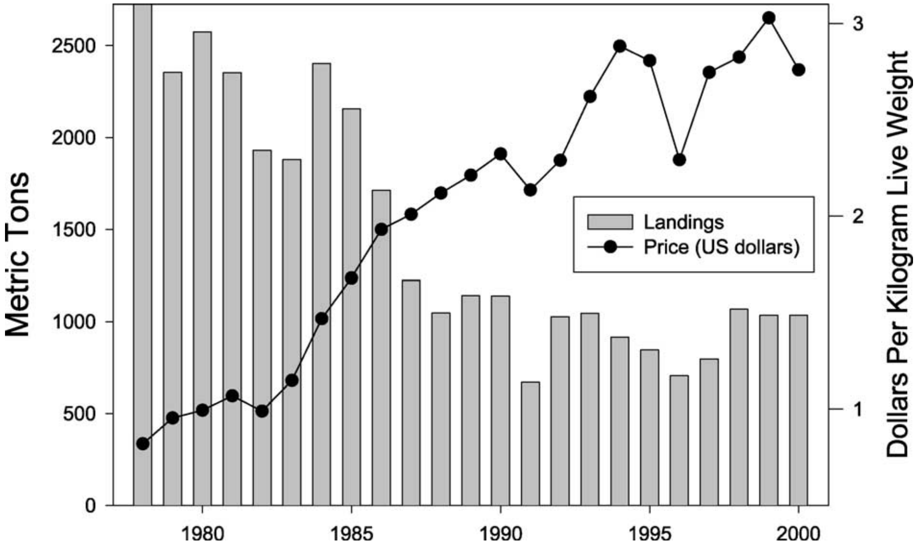


Fig. 1. Annual landings and economic value of soft-shell clams in Maine (DMR, 2000a).

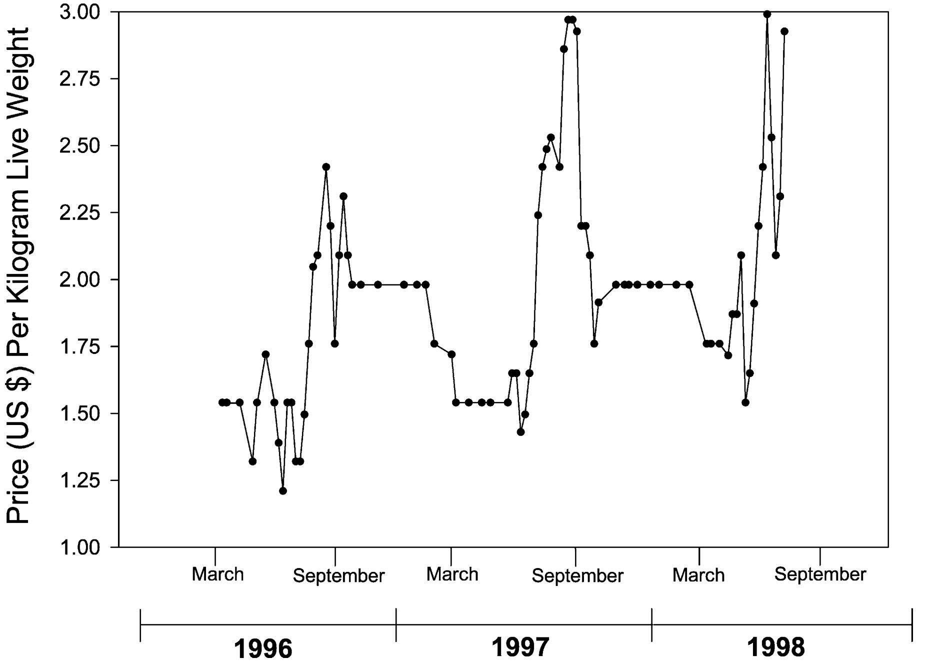


Fig. 2. Seasonal price fluctuation of live clams paid to clam harvesters by Carver's Shellfish, (Beals, ME) from 1 March 1996 through 25 August 1998.

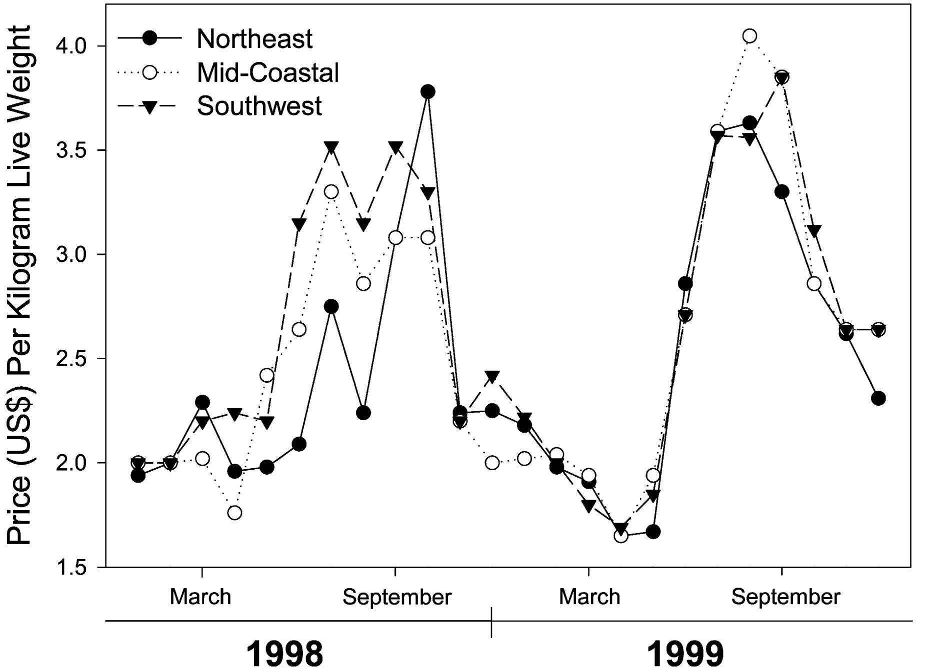


Fig. 3. Average monthly price of live clams paid to clam harvesters by shellfish dealers in three coastal regions of Maine: Northeast = Washington County; Mid-Coastal = Lincoln County; Southwest = Cumberland County.

Here, I describe a series of field trials conducted in eastern Maine during the spring and summer of 1996 in which I impounded commercial size soft-shell clams at densities between 720 and 850/m^2 using cages and nets to protect animals from predators. In 1997 and 1988, protocols were transferred to commercial clammers in two Maine communities with varying degrees of success. The results indicate that impounding adult *M. arenaria* has the potential to increase the economic value of the clam fishery in Maine. This potential will likely not be realized by the industry within the near future because the social and political climate in Maine is strongly opposed to privatizing intertidal areas, where 99% of the commercial crop is harvested.

2. Materials and methods

2.1. Study sites

The study was conducted in eastern Maine, USA from 28 April to 28 August 1996 at an intertidal mudflat (Flake Point Bar [FPB], Jonesport; Latitude 44°37′ N, 67°34′ W) and shallow subtidal lobster impoundment (Bayer, 1984; Donahue et al., 1999) (Perio Point [PP], Beals; Latitude 44°31′ N, 67°36′ W). The intertidal site was located between mid and high tide levels along the shore in muddy sand sediments (mean $\phi \pm 1$ s = 1.91 ± 0.15;

$n = 2$). No sediment samples were taken within the lobster impoundment, but, qualitatively, sediments were coarser than those at Flake Point Bar, as they contained more gravel, cobble, and dead valves of *M. arenaria*.

2.2. Field experiments

Twelve 122 × 92-cm plots of sediment (arranged in a 2 × 6 matrix with ca. 2-m spaces between rows and columns) were re-worked to a depth of 15 cm using a clam hoe (sensu Robinson and Rowell, 1990) at FPB on 28 April 1996. Soft-shell clams (mean shell length [greatest anterior to posterior distance]—SL ± 1 S.E. = 56.2 ± 0.56 mm, $n = 180$; range = 43.9 to 75.4 mm; Fig. 4a) were directly spread out on the surface of six of the re-worked plots with hands. Three plots each received a volume of clams nearly equal to one-half bushel (ca. 11.4 kg), while the other three received approximately one bushel (ca. 22.7 kg) (Table 1). All six plots of clams were covered with a piece of flexible netting (0.64-cm aperture and measuring 150 × 150 cm; InterNet, North Minneapolis, MN). The edge of the netting was placed into a 15-cm wide × 15-cm deep furrow dug around the periphery of each plot. The diggings from the furrow were backfilled on top of the edge of the net holding it in place for the duration of the test. A styrofoam float (with a 10-cm diameter × 8-cm thickness) was affixed to the underside of each piece of netting so that the netting would billow above the sediments during periods of tidal inundation (Beal (1994) found that growth of juveniles of *M. arenaria* was adversely affected when planted beneath nets of similar size without floats due to excessive siltation). Sediment from the remaining six plots was completely excavated (15 cm) and placed adjacent to each plot. Cages (122 × 92 × 15 cm), made from 12-gauge vinyl coated wire with an aperture of 0.64 × 1.27 cm, were then positioned within the excavated plot so they were flush with the mudflat surface, and sediments shoveled into each. Approximately one-half bushel of clams was spread on the sediment surface (as above) within each of the three cages, and one bushel was added to each of the three remaining cages (Table 1). Treatments (meshed—1 bu; meshed—1/2 bu; caged—1 bu; caged—1/2 bu) were randomly assigned to positions within the matrix. Netted areas and cages at FPB, which took 5 and 15 min, respectively, to establish, were exposed between 2 and 3 h on each period of low water during the daily semidiurnal tidal cycle. At PP, six cages (same dimensions as above) were established during low tide on 29 April 1996. One-half bushel of clams was spread on the surface of each of the three cages, while the other three each received approximately one bushel of clams (mean SL ± 1 S.E. = 56.4 ± 0.66 mm, $n = 90$; range = 45.8–73.9 mm; Table 1; Fig 4b). The tidal impoundment at PP remained unused (i.e., without lobsters) during the experimental period, and, there was always 1–2 m of water covering the cages at all times.

All clams used in these trials were commercially harvested from intertidal flats in the extreme east coastal Maine (Perry [Latitude 44°56′ N, 67°5′ W] and Eastport [Latitude 44°55′ N, 67°2′ W]) on 27 April 1996. Clams were transported in a refrigerated (4 °C) truck to a commercial shellfish dealer's processing plant located in the town of Beals, ME (Carver Shellfish). Animals were washed with cold freshwater and some dead and cracked individuals were removed by processing plant staff before being placed into 1-bushel, covered, wooden containers or crates. Fourteen bushels of a total of 85 bushels processed

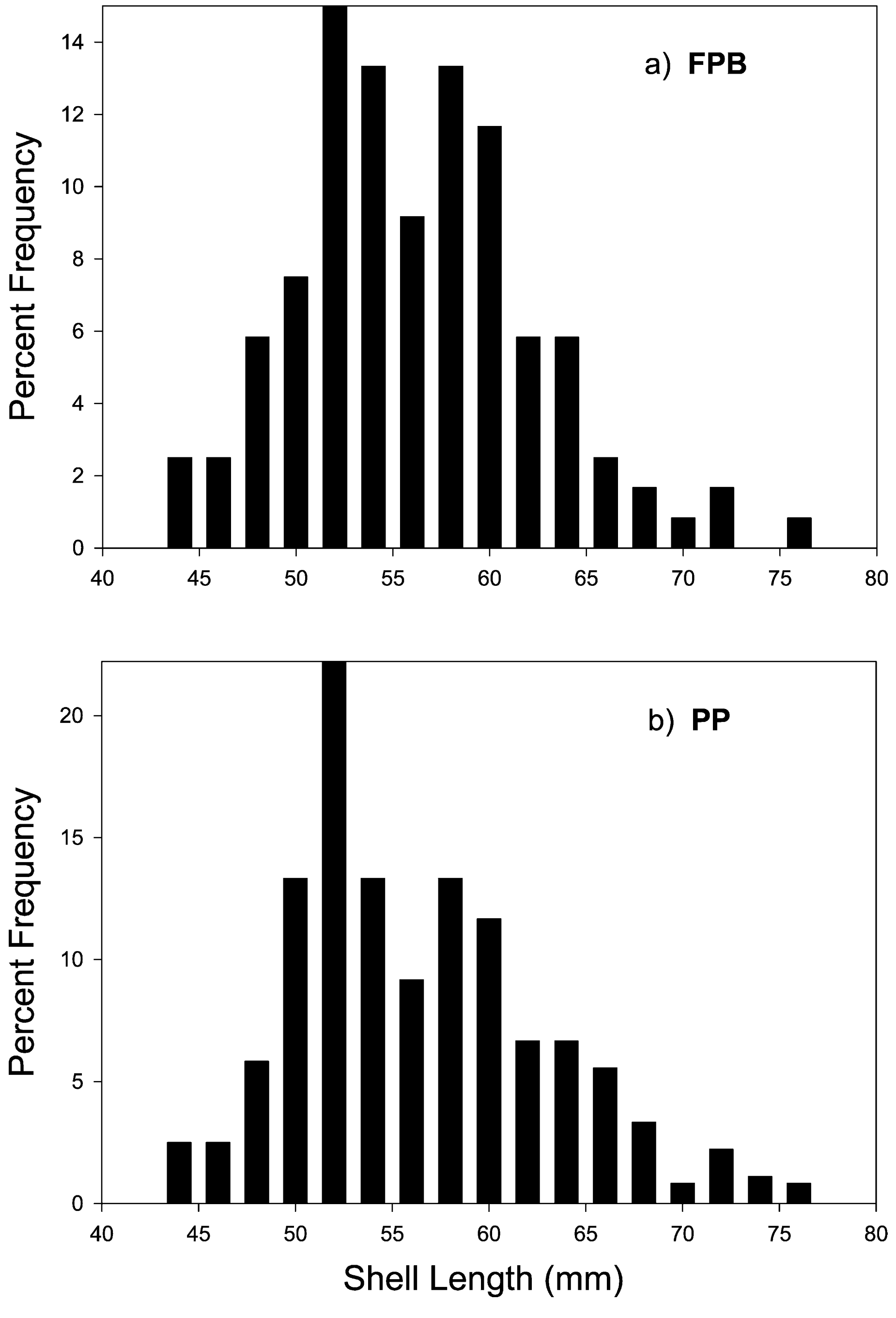


Fig. 4. Initial size-frequency distribution (28 April 1996) of commercial size *M. arenaria* used in field impounding trials (a) in the upper intertidal at FPB (Flake Point Bar, Jonesport, ME; $n = 180$, $\bar{x} = 56.2 \pm 0.56$ mm) and (b) in the shallow subtidal of a lobster impoundment at PP (Perio Point, Beals, ME; $n = 90$, $\bar{x} = 56.4 \pm 0.66$ mm).

Table 1
Initial demographics of commercially harvested *Mya arenaria* used in field impoundment studies at two sites (Flake Point Bar, Jonesport = FPB; Perio Point, Beals = PP) in eastern Maine (28 April 1996)

Groups	Total number	Total wet weight	Number cracked/dead	Total wet weight cracked/dead	Number of clams impounded	Wet weight of clams impounded	Mean shell length (mm) (± 1 S.E.)
FPB							
1	920	22.1	39	0.8	881	21.3	57.5 (1.15)
2	888	21.8	44	0.8	844	21.0	57.4 (1.73)
3	887	21.8	26	0.5	861	21.3	57.3 (1.48)
4	968	21.9	50	0.9	918	21.0	55.9 (1.82)
5	945	21.8	51	0.9	894	20.9	54.5 (1.65)
6	854	21.7	47	1.1	807	20.6	59.9 (1.52)
A(1)	971	21.9	41	0.6	466	10.8	55.7 (1.40)
A(2)					464	10.5	55.1 (1.23)
B(1)	935	21.9	30	0.6	459	10.7	54.9 (1.19)
C(2)					446	10.6	55.2 (1.26)
C(1)	986	21.8	42	0.5	475	10.6	54.1 (1.65)
B(2)					469	10.6	53.9 (1.72)
PP							
1	992	22.4	33	0.9	959	21.5	54.4 (1.50)
2	956	22.3	31	0.9	925	21.4	55.7 (1.87)
3	893	22.3	39	1.0	854	21.3	55.1 (1.42)
A(1)	926	22.2	45	1.1	443	10.6	58.3 (1.57)
A(2)					438	10.5	58.7 (1.80)
B(1)	985	22.4	36	1.0	465	10.7	55.4 (1.43)

Clams were counted and weighed after commercial processing for wholesale distribution. Live clams were directly added to 1.12 m^2 re-worked sediment patches, covered with flexible netting, or to re-worked sediment within complete 1.12 m^2 cages. Groups denoted by a number represent treatment volumes of ca. 1 bushel, whereas groups denoted by a letter and number represent treatment volumes of ca. 1/2 bushel (1 bushel = 22.7 kg). Weights are in kilograms. Number of clams measured per bushel = 15.

on 27 April were haphazardly selected. All clams from each bushel crate were counted and the total was weighed to the nearest 0.1 kg (Tara electronic scale). Although processed for wholesale, there was a number of dead and cracked clams in each bushel crate. These were removed and weighed prior to the field experiment, and, the mass of all live clams that were used in the field weighed (as above; Table 1). Five of the fourteen bushels were approximately divided in half (by weight) and these 1/2-bushel containers and the remaining nine 1-bushel crates were held overnight at Carver Shellfish in a walk-in cooler (4 °C). To establish an initial size distribution for each of the 12 plots at FPB and 6 plots at PP, 15 clams were haphazardly chosen from each bushel and half-bushel container prior to field impounding and measured (SL) to the nearest 0.1 mm using vernier calipers. At FPB, there were no initial differences in mean SL of clams added to the 12 plots ($F = 1.57$; $df = 11, 168$; $P = 0.1122$). Similarly, no differences initially existed in mean SL of clams added to the six plots at PP ($F = 1.04$; $df = 5, 84$; $P = 0.4007$). Fisher's Exact Tests on initial size distributions between plots revealed no significant differences at FPB ($P = 0.1043$) or at PP ($P = 0.2429$).

On 27 and 28 August 1996, sediments that contained live and dead clams were removed by hand from cages at both sites. In addition, I used a clam hoe to excavate the meshed plots at FPB and removed all live and dead clams that I could find. A total of 15 live clams (sampled haphazardly from a bulk pile of all living clams), all clams cracked or otherwise damaged in the process of sampling, and all dead clams from all cages and netted plots were measured (as above) and all live clams (damaged and undamaged) were weighed to the nearest 0.1 kg. I included cracked or damaged clams in the final weight measurements from each netted and caged plot because the number of damaged individuals averaged less than seven animals per plot at both sites (see Results). The price paid to harvesters on 28 April 1996 by Carver Shellfish, Beals, ME was \$1.30/kg, whereas the price paid to harvesters on 28 August 1996 was \$2.40/kg (Fig. 2).

2.3. Statistics

A two-factor (fixed) model I ANOVA on the arcsine-transformed percent survival, untransformed length, and $\log_{10}$-transformed weight data was used to test for plot type (cage vs. netting) and clam volume (1- vs. 1/2-bushel) effects at FPB. Weights of clams from cages and plots that were initially stocked with 1/2 bushel were doubled, prior to log transformation. In both cases, the transformations normalized the data (Shapiro–Wilks test (SAS Institute, 1989); Sokal and Rohlf, 1995). Clam volume effects were tested on survival, length, and log-transformed weight data from cages at PP using a single-factor ANOVA. I did not compare sites in an overall linear model because the difference in exposure times was not equal between FPB and PP. A comparison of initial and final size-frequency distribution of live (damaged and undamaged) clams was performed on data from both sites using a log-likelihood G-test of independence (Sokal and Rohlf, 1995).

2.4. Technology transfer to commercial harvesters

To determine whether the field methodologies that were used in the 1996 field experiment were transferable to industry, I worked directly with clam harvesters in two communities. Two field trials were conducted by clammers near the low intertidal of Montsweag Creek in Wiscasset, ME (43°57′ N, 69°42′ W) from 21 June (price=\$2.42/kg) to 31 August (price=\$3.30–\$3.74/kg) 1997 and from 26 April (price=\$1.98/kg) to 8 August (price=\$3.74/kg) 1998. In 1997, two field assistants and I helped several clammers to establish eight vinyl-coated wire cages ($122 \times 92 \times 13$ cm deep with apertures, as described above) in very soft mud. Cages were shallower than those that were used in the 1996 field experiments because it was found that survival rates were no different in these cages than in ones with a depth of 15 cm (Beal, unpublished data). Each cage received 22.7 kg of live clams that had been dug within 48 h of initiating the trial. Clams were stored in cool, damp places (i.e., commercial coolers, basements of houses, under tarpaulin on the north side of houses, and in onion bags submerged in ambient seawater), but it was not possible to standardize storage conditions. In 1998, clammers established by themselves 10 cages with clams ranging from 18.6 to 25.9 kg/cage. Clams in each cage were harvested by two people standing in 15–20 cm of water who lifted the cage from the sediments, sieved the sediment by shaking the cage vigorously, and collecting the clams from the cage after walking it to the shore. In both years, clams were weighed in August by a commercial shellfish dealer (to the nearest 0.1 kg) at the point of sale.

On 15 April 2000 (price=$1.98/kg), I assisted a commercial clam harvester from Perry, ME to establish a single wire cage (similar to those used in Wiscasset) near the upper intertidal of East Bay. Clams were harvested from an adjacent mudflat in the same community and placed in the cage on the same day. Two additional field cages were deployed during the next week and clams were placed in them on the same day (Dupe, Perry, ME, personal communication). Cages were stocked with clams weighing from 22.9 to 23.6 kg. Clams were harvested from the three cages and weighed during the first week of August 2000 (price=$4.40/kg) when they were sold at a commercial buying station.

3. Results

3.1. Field experiments

The mean survival (± 1 S.E.) that was pooled across all treatments for the 4-month experimental interval was 91.7 ± 0.79% ($n=12$) at FPB and 91.6 ± 1.33% ($n=6$) at PP

Table 2
Percent survival and final wet weights for clams impounded at Flake Point Bar, Jonesport, ME (FBR) and Perio Point, Beals, ME (PP) for the period 28 April to 28 August 1996

Group	Treatment		Initial number	Final number	Percent survival	Initial weight	Final weight	[a]ΔWeight	Δ%Weight
	Plot type	Volume							
FPB									
1	Netting	1 bu	881	795	90.2	21.3	20.6	– 0.7	– 3.3
2	Netting	1 bu	844	727	86.1	21.0	18.9	– 2.1	– 10.0
3	Netting	1 bu	861	797	92.6	21.3	21.9	+0.6	+2.8
4	Cage	1 bu	918	843	91.8	21.0	21.8	+0.8	+3.8
5	Cage	1 bu	894	830	92.8	20.9	21.2	+0.3	+1.4
6	Cage	1 bu	807	739	91.6	20.6	20.3	– 0.3	– 1.5
A(1)	Netting	1/2 bu	466	417	89.5	10.8	10.3	– 0.5	– 4.6
A(2)	Netting	1/2 bu	464	419	90.3	10.5	10.4	– 0.1	– 1.0
B(1)	Netting	1/2 bu	459	428	93.2	10.7	10.7	0.0	0.0
B(2)	Cage	1/2 bu	469	445	94.9	10.6	11.1	+0.5	+4.7
C(1)	Cage	1/2 bu	475	460	96.8	10.6	11.4	+0.7	+7.5
C(2)	Cage	1/2 bu	446	403	90.4	10.6	10.5	– 0.1	– 0.9
PP									
1	Cage	1 bu	959	904	94.3	21.5	21.8	+0.3	+1.4
2	Cage	1 bu	854	783	91.7	21.3	21.1	– 0.2	– 0.9
3	Cage	1 bu	925	834	90.2	21.4	21.2	– 0.2	– 0.9
A(1)	Cage	1/2 bu	443	399	90.1	10.6	10.4	– 0.2	– 1.9
A(2)	Cage	1/2 bu	438	382	87.2	10.5	10.2	– 0.3	– 2.9
B(1)	Cage	1/2 bu	465	448	96.3	10.7	11.4	+0.7	+6.5

Plot type refers to 1.12 m^2 patches of re-worked sediment to which live clams were added. Netting = flexible, with 6.4 mm aperture. Cage = 122 × 92 × 15 cm constructed of vinyl-coated wire with apertures of 0.64 × 1.27 cm. Volume refers to amount of live clams added to each sediment patch (1 bu = 22.7 kg). Group numbers and letters are the same as in Table 1. Weights are in kilograms.

[a] ΔWeight and Δ%Weight are based on the wet weights of live clams impounded, not on the total wet weight (Table 1), which included individuals that were dead and/or with cracked valves.

(Table 2). At both sites, survival was independent of treatment as both main factors (plot type [cage vs. netting] and volume [1 bu vs. 1/2 bu]) and the interaction term were not significant (P>0.10). No treatment effects were observed for either final mean shell length or final weight at both sites (P>0.10). At FPB, final mean SL of living and cracked individuals was 55.9 ± 0.43 mm (n = 258; range = 42.5–72.6 mm) compared to an initial mean of 56.2 mm (see Materials and methods). ANOVA indicated no difference in mean lengths between live individuals and those that had been alive but were cracked during sampling; F = 0.05, df = 1, 168, P = 0.8154. A G-test of independence, comparing initial and final size frequency distributions of clams at FPB, also indicated that no significant shell growth had occurred during the field test (G = 11.64, df = 9, P = 0.2344). At PP, similar findings occurred. That is, the final mean SL of living and cracked individuals was 55.8 ± 0.91 mm (n = 132; range = 47.6–69.9 mm) compared to an initial mean of 56.4 mm (see Materials and methods). Also, there was no difference between initial and final size

Table 3
Results from field trials of commercial clam harvesters

Cage	Wet weight of clams impounded	Final wet weight	ΔWeight	Initial price/kg	Final price/kg	ΔPrice	Amount ($) gained due to impounding[a]
1997							
1	22.7	20.0	– 2.7	2.42	3.74	+ 1.32	19.87
2	22.7	20.0	– 2.7	2.42	3.74	+ 1.32	19.87
3	22.7	21.4	– 1.3	2.42	3.74	+ 1.32	25.10
4	22.7	20.9	– 1.8	2.42	3.74	+ 1.32	23.23
5	22.7	20.0	– 2.7	2.42	3.30	+ 0.88	11.07
6	22.7	20.0	– 2.7	2.42	3.30	+ 0.88	11.07
7	22.7	19.1	– 3.6	2.42	3.30	+ 0.88	8.10
8	22.7	11.8	– 10.9	2.42	3.30	+ 0.88	– 15.99
1998							
1	25.9	23.0	– 2.9	1.98	3.74	+ 1.76	34.74
2	25.9	23.0	– 2.9	1.98	3.74	+ 1.76	34.74
3	23.2	16.1	– 7.1	1.98	3.74	+ 1.76	14.28
4	23.2	16.5	– 6.7	1.98	3.74	+ 1.76	15.77
5	18.2	4.5	– 13.7	1.98	3.74	+ 1.76	– 19.21
6	20.5	5.2	– 15.3	1.98	3.74	+ 1.76	– 21.14
7	17.0	16.0	– 1.0	1.98	3.74	+ 1.76	26.18
8	17.6	16.2	– 1.4	1.98	3.74	+ 1.76	25.74
9	20.5	15.9	– 4.6	1.98	3.74	+ 1.76	18.88
10	18.6	13.2	– 5.4	1.98	3.74	+ 1.76	12.54
2000							
1	23.6	22.8	– 0.8	1.98	4.40	+ 2.42	53.59
2	22.9	22.3	– 0.6	1.98	4.40	+ 2.42	52.78
3	22.7	25.4	+ 2.7	1.98	4.40	+ 2.42	66.81

All clams were impounded within vinyl-coated wire cages (122 × 92 × 13 cm) with 0.64 × 1.27-cm apertures. Weights are in kilograms (1997 and 1998 involved eight and six clammers, respectively, from Wiscasset, ME. 2000 involved one clammer from Perry, ME). Prices are in US dollars ($).

[a] Amount = Price received for impounded clams in August minus price that would have been received had clams been sold in the spring immediately after commercial harvest.

frequency distribution at PP ($G=13.29$, $df=9$, $P=0.1499$). Final weight (Table 2) did not significantly differ from initial weight at either site (paired *t*-test: $T_{FPB}=0.29$, $P>0.75$; $T_{PP}=-0.10$, $P>0.75$). Valves of dead clams at both sites showed no visible signs of damage such as drill holes from moon snails, *Euspira heros*, or margin chipping that could be attributed to green crabs, *Carcinus maenas*, or rock crabs, *Cancer irroratus*. There was no significant difference in the mean shell length between the initial size and the size of dead valves at either site ($P>0.25$).

3.2. Transfer trials with commercial harvesters

Clams impounded by commercial harvesters in Wiscasset lost, on average, 3.55 ± 1.08 kg in 1997 and 6.10 ± 1.55 kg in 1998 from the beginning to the end of the field trial (Table 3). These amounts were significantly different from zero (paired *t*-test: $T_{1997}=3.23$, $P=0.013$; $T_{1998}=3.95$, $P=0.003$). In both years, however, the average weight that was lost during the impounding period would have been closer to zero if not for a single individual (cage 8 in 1997 and cages 5 and 6 in 1998—see Table 3 and Discussion). In both years combined, clammers gained, on average, \$13.60 ± \$3.94 ($n=18$) per cage by impounding clams rather than selling them when first harvested (see footnote from Table 3 for calculation). These calculations did not consider the cost of the cage, handling of the clams after harvest, or the deployment of cages and clams.

Clams impounded in Perry in 2000 did not lose weight (Table 3; paired *t*-test: $T=-0.38$, $P=0.739$) and the price difference between the beginning of the impounding period in April and the August sale date resulted in an average gain of \$57.73 ± \$4.55 per cage.

4. Discussion

Field experiments conducted in eastern Maine with commercial size soft-shell clams demonstrate that impounding large volumes of clams in relatively small spaces is biologically feasible. Further, the results suggest that successful impounding of clams can occur in disparate environments (i.e., soft-bottom intertidal and shallow subtidal sites). There is a financial incentive for this culture practice by clammers, shellfish dealers, or other entrepreneurs because of the disparity in the price for live animals that occurs each year from the spring through the summer (ca. 4 months; Figs. 2 and 3). For example, during the period between April and August 2000, prices per kg live weight in eastern Maine increased to 122% from \$1.98 to \$4.40 (Table 3).

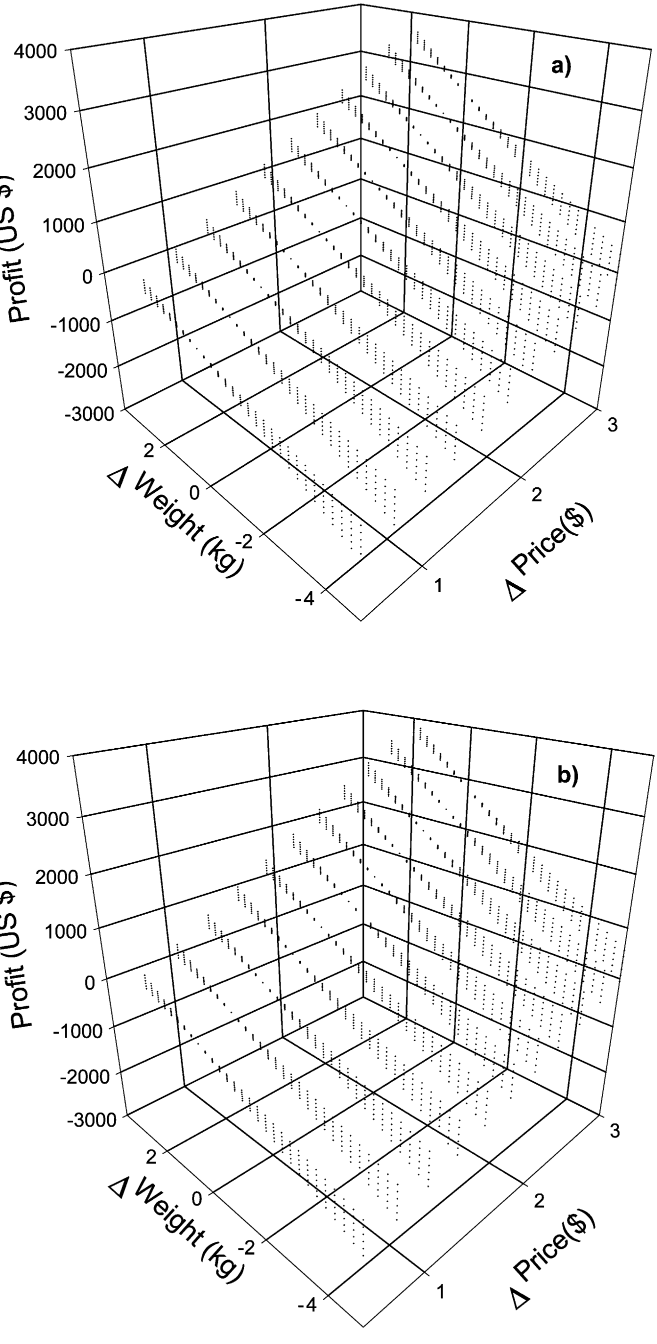
At FPB and PP, there was no difference in the survival of the clams ($\bar{x}=56$ mm) planted at ca. 800–950 per plot (i.e., 725–860/m^2, or 128 kg/m^3) and those planted at ca. 400–475 per plot (i.e., 362–430/m^2 or 65 kg/m^3). Also, at FPB, there was no difference in the survival of the clams between those placed on the sediments and covered with flexible netting and those that were placed on the sediments inside a cage. Although cages were significantly more expensive than nets with attached floats (\$28.00—Friendship Trap, Columbia Falls, ME—vs. \$0.75), the amount of time that was spent harvesting the clams protected with netting with a traditional clam hoe (Robinson and Rowell, 1990) was nearly three times that spent for harvesting clams from the cages independent of stocking density (45 vs. 15 min). This indicates that in terms of time alone, using cages stocked at densities up to 860/m^2 would be preferred over establishing clams in plots that were protected with netting.

Information from the 1996 field experiments was transferred to clammers in two communities along the Maine coast. In 1997 and 2000, clammers were assisted with deploying cages and clams. Except for a single cage in 1997 (cage 8, Table 3) in which clams were spread mistakenly along the bottom of the cage and then sediments were placed on top of them, results of impounding (Δwet weight) were similar to the field experiments at FPB and PP. In 1998, in Wiscasset (Table 3), clam mortality (based on Δwet weight) was severe in two cages (5 and 6) and relatively high in four others (3, 4, 9, and 10). Only four of the ten cages yielded results similar to the 1996 field experiments. Clammers reported that the majority of dead valves were undamaged. Several reasons exist for the poor 1998 results: (1) clams were added to the bottom of the cages, as in the case of cage 8 in 1997, and sediment was placed on top of the clams resulting in some smothering, (2) clams were held out of sediments too long or were not kept in cool, moist places prior to impounding, (3) clams were not carefully dug and there were high numbers of dead clams initially impounded, or (4) clams were consumed by a predator, such as the ribbon worm, *Cerebratulus lacteus* Leidy (Bourque et al., 1999) that leaves no discernible shell damage. The latter explanation does not seem reasonable as predation would have to have been extremely localized because all ten cages were deployed within several meters of each other. A combination of the first three reasons seems to be the most plausible. In 1997, harvesters noticed that an individual who is noted for his careful digging (i.e., minimal damage to clams during harvesting) obtained the best survival, final wet weights, and financial return (cages 3 and 4, Table 3). That individual had kept his clams submerged overnight in ambient seawater in two onion bags in the Sheepscot River near Wiscasset. The best impounding results among harvesters occurred in 2000 when the Perry clammer transferred clams to cages immediately after harvesting them.

No significant shell growth was observed at either FBP or PP in 1996 or in any of the cages deployed by clammers. In eastern Maine, 85% of the annual shell growth of hatchery-reared juveniles of *M. arenaria* typically occurs between early April and late August (Beal et al., 2001). This growth coincides well with the growth of adult clams (Beal, personal observation). It was not too surprising that clams did not grow at FPB where they were exposed to air for 2–3 h during each period of low tide, but clams also did not grow in the lobster impoundment at PP where animals were always inundated, and, therefore, capable of feeding for longer periods each tidal cycle than those at FPB. None of the cages or mesh netting was fouled at the end of the experiment and flow, apparently, was not restricted by the netting as clam growth did not differ between caged and netted animals. It is likely that clams were stocked at densities where competition for food limited their growth (sensu Peterson and Beal, 1989). Another possibility is that near-bottom, horizontal seston fluxes were high enough to reduce growth as in *Mercenaria mercenaria* (L.) (Grizzle and Lutz, 1989). Further, *Mya* spawn in eastern Maine during late May through early July (Beal, personal observation) and do so approximately 4–6 weeks earlier in Wiscasset and points south (Ropes and Stickney, 1965; Fegley et al., 1996). The decline in weight observed in most cages and netted areas in the field experiments and in the cages deployed by clammers was likely a result of mortality as well as losing both gonadal and tissue mass. Therefore, an indirect benefit of impounding adult soft-shell clams during the 4-month period from April through August might be to create spawner sanctuaries (Siddall et al., 1988). This assumes that reproductive material is released and not resorbed as in *Crassostrea gigas* (Thunberg) in Westcott Bay, Washington, USA (Davis, 1989).

Impounding commercial size soft-shell clams to create a value-added product is currently not in vogue along the Maine coast. One might ask: (1) why should clammers impound their harvest for 4 months when they could wait until late August/early September, when the price is highest during the year, to harvest and sell clams; and (2) why, if clam pounding could be profitable, are so few individuals in Maine currently engaged in these activities? Answers to these questions relate to how the clam fishery is managed in Maine. The clam fishery is the only commercial fishery in Maine that is managed at the community level, with municipalities working in partnership with the State. That is, the intertidal zone, where >99% of clams are commercially harvested, is considered a public resource, and efforts to privatize this zone have not been greeted with enthusiasm by coastal communities. There is, however, a law that was passed in the Maine State Legislature in 1905 giving rights to a community to issue municipal leases (up to one quarter of all commercial shellfishing areas within a community) to individuals or groups of individuals for the purpose of clam farming (DMR, 2000b). As of December 2000, there was only one active municipal lease (1 ha) in Maine issued by the community of Swan's Island in 1993. If general attitude and opinion about clam farming in Maine were to change, then, perhaps, commercial impoundments for clams would exist. Today, the clam fishery in Maine is year-round even though the demand is highly seasonable, as noted by changes in price per live kg that clammers receive for their product (Figs. 2 and 3). The reason why clams are harvested and sold throughout the fall and winter is that those who dig clams for a living require income throughout the year. Most harvesters are not wealthy and must sell their entire catch when it is harvested, but, if presented with an opportunity to impound all or a portion of springtime harvests, some might be willing to do so (Dupe, Perry, ME, personal communication). Without a private lease, however, anyone who impounds clams in Maine could lose his/her entire crop to vandals or thieves without recrimination. Therefore, in the present social and political climate, there is little economic incentive for anyone to impound soft-shell clams within the intertidal in Maine. It may be possible to establish clam impoundment cages in the shallow subtidal where leasing permission is granted by the state, not the community; however, to date, no attempts to create subtidal clam farms have occurred (M. Hastings, director, Maine Aquaculture Innovation Center, Orono, ME, personal communication).

Should the attitude of Maine people change with respect to intertidal leasing and the establishment of clam farms, entrepreneurs could learn to increase the value of their commercial clam harvest. One change in cage design should be made in the future. Vinyl-coated wire cages should be smaller than those that were used here and might have dimensions approximately one-half of those used in the field trials (e.g., $90 \times 60 \times 13$ cm) because these would be easier for one person working alone to hydraulically manipulate or otherwise. Fig. 5a and b shows a series of annual profit curves (based on the difference between initial and final price/kg and on Δweight/cage) for an individual who deploys 100 of these cages (at \$15 each paid evenly over a 3-year period) and stocks each with 11.4 kg


a)
b)
Profit (US $)
4000
3000
2000
1000
0
-1000
-2000
-3000
Δ Weight (kg)
2
0
-2
-4
Δ Price($)
1
2
3

(ca. 1/2 bushel) of commercial size soft-shell clams for each of the 3 years. I estimated an overhead cost of \$3.00 (Fig. 5a) and \$1.00 (Fig. 5b) per 11.4 kg (fuel, boots, license, hoe, deploying cages, harvesting cages, etc.) in addition to accounting for the commercial cost of the 11.4 kg (i.e., amount paid to a clammer) at the beginning of the impoundment period. At the lower of the two overhead costs (Fig. 5b), highest profits (i.e., >\$3000) occur only when the difference between initial and final price per kilogram is $\geq$ \$2.50 and weight increases by more than 0.5 kg. Only once did clammers experience gains in weight during the impounding interval (cage 3, year 2000, Table 3), but these were associated with initial weights>11.4 kg. It is likely that weight losses of 5–7% (0.6 to 0.8 kg) per cage would occur during the 4-month period (Tables 2 and 3). According to Fig. 5b, for weight losses < 1.0 kg/cage, profits exceeding \$1000 occur only when the difference between the initial and final price per kilogram is $\geq$ \$1.75. As with lobsters (Anonymous, 1991), one should initiate impounding when commercial prices for clams are at the lowest possible price and sell at the highest possible price. If, for example, the difference between initial and final price per kilogram is \$2.75 to \$3.00, it would be possible to generate a profit ca. \$1000 for the 100 cages with each averaging a weight loss between 3.25 and 3.50 kg (Fig. 5b).

Although clammers have been the focus of these investigations, the possibility exists that shellfish dealers or other entrepreneurs in Maine and the northeast US (where environmental and biotic conditions are similar to those in Maine) could benefit from impounding commercial size soft-shell clams. Shellfish dealers and processors, in particular, have the greatest opportunity and financial incentive to impound clams because most have large walk-in coolers and facilities to clean, grade, and, most employ part-time clammers as well as those who shuck clams. Dealers and processors may use two strategies for impounding clams. One might be to impound clams and harvest them throughout the summer for use in the fried clam and clam chowder market (i.e., shucked meats) that exists throughout the summer months in Maine (Clime and Townsend, 1993). Another strategy might be to impound clams for the late summer market when bushel prices are the highest during the year as was done in the field trials described here.

The purpose of this work was to determine whether it was biologically feasible to impound commercial size soft-shell clams in Maine's intertidal flats to take advantage of considerable differences in price of live individuals between early spring and late summer. Survival rates>90% demonstrated the biological efficacy of this practice, and, there is limited field data indicating that under certain circumstances, impounding clams can be cost-effective. It remains to be seen, however, if any of the sectors in the clam industry (e.g., harvesters, dealers, processors) will adopt these practices that are so widely accepted

Fig. 5. Theoretical profit curves (years 1–3) based on impounding 11.4 kg of live, commercial size clams within each of 100 impoundment cages (90 × 60 × 13 cm) from April to August. ΔPrice (\$) is the difference in price per kg of live clams during the impoundment period and ranges from \$0.50 to \$3.00 in 11 inclusive steps of \$0.25. ΔWeight (kg) is the difference between the initial and final wet weight (kg) per cage (a negative value for ΔWeight indicates a net loss) and ranges from +2 to −5 kg in 0.25kg increments. The six vertical points for a given ΔPrice and ΔWeight represent an initial price per kg of live clams in \$0.25 increments from \$1.50 to \$2.75. Profits (US\$) are based on the following assumptions: (1) cages (\$15 each) are paid for in annual increments of \$500, (2) clams harvested prior to impounding are paid for at commercial rates, and (3) an overhead cost of (a) \$3.00 and (b) \$1.00 is deducted per cage to compensate for costs associated with fuel, boots, licenses, hoes, and deploying and harvesting cages.

in the lobster industry in Maine. The primary difference between lobster and clam impounding is that the former occupies space in the intertidal that is composed of hard bottoms where clams do not reside, or, in soft bottom areas that are closed to shellfishing due to fecal contamination (Beal, personal observation) (since lobster and lobster meat is not subjected to National Shellfish Sanitation Program standards, lobster impoundments may be located in intertidal areas that are closed to shellfishing due to high fecal coliform counts). Clam impounding requires portions of the intertidal with water quality that is considered safe in terms of fecal coliforms (Jones and Summer-Brason, 1998) because, ultimately, the clams must either be sold as a shucked product or consumed directly (steamer clam market). Because uncontaminated areas of the intertidal in Maine are managed by coastal communities and have been considered public fishing grounds since the mid-1800s (Ellis and Waterman, 1998), there is strong sentiment against privatizing these public areas and ultimately restricting access to a public resource.

The economic value of Maine's marine resources is linked to developing value-added products. New grow-out technologies for soft-shell clams through field impounding potentially offers an alternative product that could enhance the overall value of Maine's soft-shell clam fishery. Given the social and political climate that exists currently in that state, it is unlikely that implementing this practice will occur in the private sector any time in the near future. Rather, should impounding gain economic and social acceptance, it is likely to be used as a source of income for community-based management efforts (Beal, 1994), or resource enhancement if the concept of spawner sanctuaries (sensu McCay, 1988) is valid for this species.

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