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ESTIMATES OF LOSSES ASSOCIATED WITH FIELD DEPURATION (RELAYING) OF *MERCENARIA* SPP. IN THE INDIAN RIVER LAGOON, FLORIDA

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ABSTRACT Experiments were performed during June 1987 and February 1988 to test the effects of field depuration, or "relaying," on the mortality rates of *Mercenaria* spp. in the Indian River lagoon, Florida (USA). Mortality rates of clams in open 1.0 m^2 plots were compared with those of clams in plots protected by predator-exclusion cages over periods of two and four weeks. An additional experiment examined the effect of fences on rates of clam loss and demonstrated that loss from open plots could be attributed to predation. Mortality due to predation was significantly higher in open plots, and brachyuran crabs appeared to be an important cause of this mortality. Mortality was not significantly different between summer and winter, and was related to the elapsed time between the initiation of relaying and reharvest. Because of mortality and reharvest losses in harvest efficiency, relaying as practiced in the Indian River lagoon may be of minimal economic benefit to clam fishermen.

KEY WORDS: *Mercenaria*, hard clam, relaying, mortality, predation

INTRODUCTION

Field depuration is commonly practiced by clammers and oystermen in the United States. Field depuration involves gathering bivalves from waters conditionally approved, restricted, or prohibited for shellfishing and moving them to approved waters for a minimum of 14 days (USPHS 1965) to allow the bivalves to purge their gut of enteric bacteria. This process is generally termed "relaying," although relaying may also mean moving bivalves between open areas to promote growth. Relayed clams are generally held on submerged bottom lands leased to private shellfish operations. Alternatively, clams may be moved ashore to an approved closed-cycle depuration plant. Relaying of hard clams, *Mercenaria* spp.,[1] is practiced in the Indian River lagoon (Fig. 1), on the east central coast of Florida, under permit from the Florida Department of Natural Resources.

In recent years, a sudden and unanticipated increase in *Mercenaria* landings from the Indian River lagoon has provided a substantial commercial supply of hard clams. Almost 46% of the commercially exploitable area of the lagoon is composed of waters unapproved for harvesting, and depuration has allowed for the harvest of many clams from these areas. However, because relaying involves disturbance and concentration of the clams, losses due to stress and predation during the relay process may occur. The present study was designed to estimate the short-term survivorship of relayed clams. These estimates are then used in a bioeconomic model to determine the most economical method for independent Indian River clammers to deliver clams to seafood wholesalers.

METHODS

The study site, a shellfish lease north of Grant, Florida (Fig. 1), had a depth of approximately 1.5 m, a muddy sand substrate, and no submerged aquatic vegetation. The site is representative of benthic habitats in this region of the Indian River lagoon (Arnold and Marelli, unpubl. data). Experiments were conducted during June 1987 (summer) and February 1988 (winter). Each experiment involved twelve 1.0 m^2 plots; six plots were open, marked only with stakes and twine, and six plots were enclosed by predator-exclusion cages. Each cage consisted of a 1.0-m × 1.0-m × 0.5-m aluminum frame covered with 1-cm × 1-cm polyethylene mesh. The bottom edges of the cages penetrated the substrate to a depth of 1–2 cm. Clams in the size range 50 to 75 mm shell length (SL = maximum anterior posterior distance), obtained from commercial clammers, were labeled by painting an orange spot on one valve, and were held overnight[2] out of water. One hundred clams were placed in each plot on the following day and allowed to rebury themselves. This density was determined by personal observation to be equal to or lower than densities used in Indian River relay operations.

Three caged plots and three open plots were harvested two weeks after relaying, and the remaining plots were reharvested after four weeks. Harvest consisted of handraking as many clams as possible from each plot and then clearing the plot with a venturi-driven suction dredge to

[1]The Indian River lagoon contains two sympatric species of *Mercenaria*, *M. mercenaria* and *M. campechiensis*, plus hybrids (Dillon & Manzi 1989). These are very difficult to separate morphologically, and we have chosen to use the generic name *Mercenaria* herein.

[2]Clams being relayed generally are not held out of water overnight. Since *Mercenaria* spp. can survive in air for weeks, however, it was reasoned that 12 hours out of water would not significantly increase mortality.

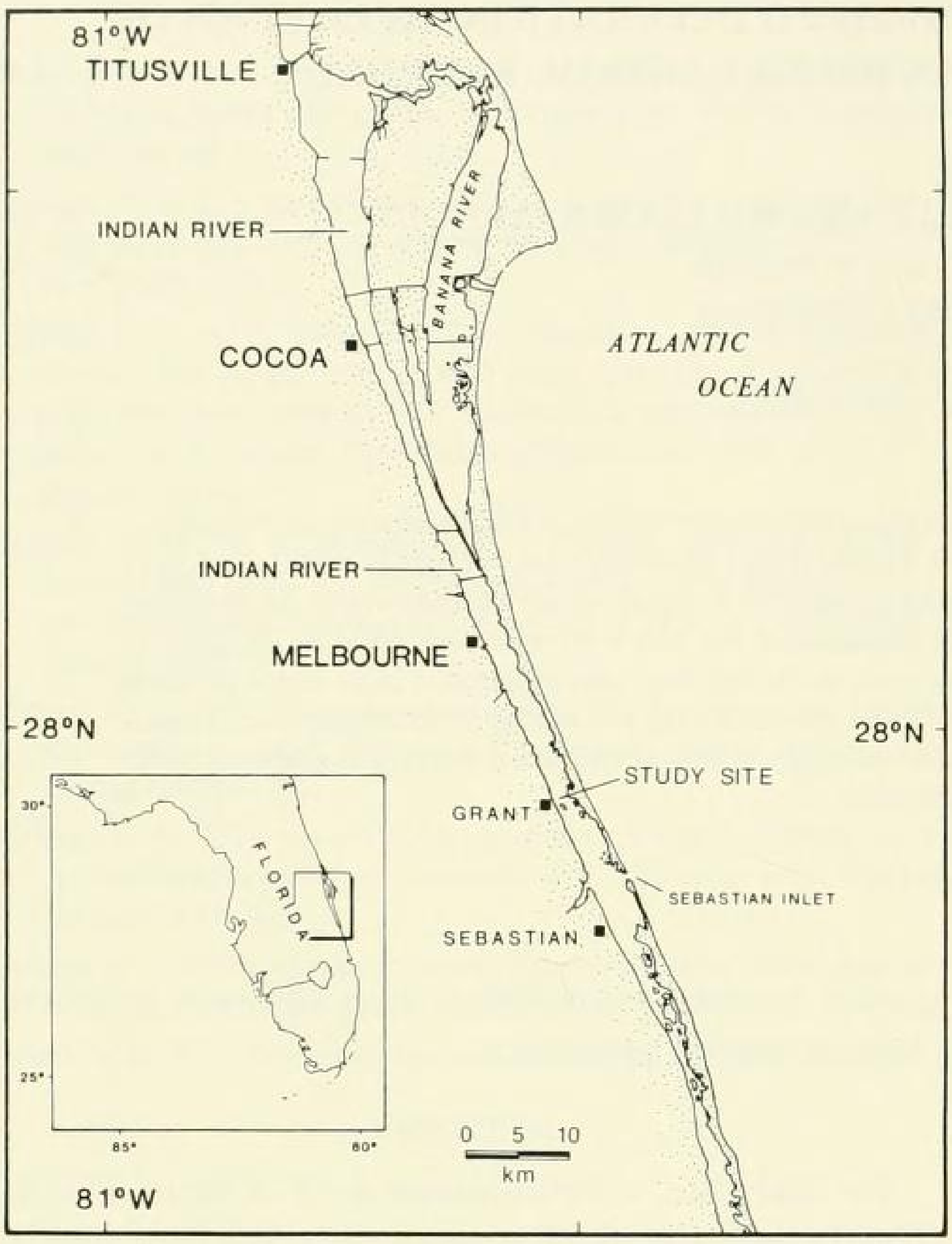

Figure 1. The Indian River lagoon. The clam fishery is located principally between Titusville and Sebastian.

collect any clams missed by raking. All labeled clams that were recovered were counted and recorded. Shells of dead clams were examined for indications of causes of mortality (Magalhaes 1948, Carriker 1951, Landers 1954, Paine 1962, Vermeij 1978, Peterson 1982). Mortality was calculated as follows: [number dead ÷ number relayed] × 100. Total loss was calculated as follows: [(number dead + number missing) ÷ number relayed] × 100. The results of this experiment were analyzed using a three-way completely randomized analysis of variance (ANOVA) on untransformed data.

An additional experiment was performed in March and April, 1989 to determine the effect of lateral movement on the unexplained loss of clams (number missing) from open plots. This experiment used 3 open plots, as described previously, and 3 fenced plots. Fences were constructed of 15 cm high, 1 m long strips of polyethylene mesh supported by pressure-treated stakes and pressed 4 to 5 cm into the substrate. Ninety-five marked clams were placed in each plot on March 2 and were reharvested on April 6.

Data from this experiment were analyzed using an unbalanced one-way ANOVA (SAS Institute, Cary, NC, GLM procedure) since cell sizes were unequal. Differences in numbers of missing clams among treatments were tested for significance using a Student-Newman-Keuls mean procedure.

RESULTS

Data from the experiment estimating the effect of fencing on the percentage of missing clams (Table 1) were compared with data collected during the winter of 1988 on the percentage of clams missing from 4-week caged plots. Plot condition (caged, fenced, or open) had a significant effect on clam losses (Table 2). Fenced and open plots were statistically indistinguishable with respect to the percentage of missing clams, and many fewer clams were recorded as missing from caged plots (Table 3). Following the procedure of Underwood (1981), which was based on Winer (1971), we calculated the probability of a type II error at 0.09, making it highly unlikely that a lack of significant difference between the cage and fence treatments was due to a lack of replication. These results demonstrate that missing clams can be considered to be mortalities.

In the comparisons of open and caged plots, mortality was similar in summer and winter experiments (Fig. 2). Mean mortality was greater in open plots than in caged plots during both summer and winter experiments (Tables 4 and 5). Examination of the shells of confirmed mortalities indicated that brachyuran crabs were an important cause of mortality in both seasons. No evidence of predation by whelks was observed, and 2.3% of clams in all treatments died from unspecified causes.

TABLE 1.

Survivorship, percentage missing, and mortality caused by crabs on *Mercenaria* spp. transplanted to open and fenced plots and harvested after 5 weeks, March–April 1989. Mortality represents confirmed deaths, and is subdivided by specific cause: crab mortality or undetermined reasons. All values are percentages.

Plot Condition	Replicate	Survivorship	Mortality	% Missing	Crab Mortality	Other Mortality
Open	1	78.9	1.1	20.0	1.1	0
	2	86.3	1.1	12.6	1.1	0
	3	78.9	1.1	20.0	1.1	0
Fenced	1	78.9	0	21.1	0	0
	2	86.3	3.2	10.5	2.1	1.1
	3	86.3	1.1	12.6	0	1.1

TABLE 2.

Analysis of variance for effects of fencing, caging, and open plots on percentage of *Mercenaria* spp. lost following transplantation and relaying.

Source	df	SS	MS	F	p-value
Plot Condition	2	485.73	242.87	15.21	$p < 0.005$
Residual	9	143.74	15.97		
Total	11	629.47			

Analysis of the results of the experiment examining mortality in open and caged plots indicated that predator-exclusion cages significantly reduced mortality, and that mortality rates of *Mercenaria* individuals were not significantly different either between seasons or across harvest times (Table 6).

DISCUSSION

The results of this study establish that relayed hard clams suffered losses of 14% in unprotected plots during the course of this experiment. Clams located within predator-exclusion cages experienced reduced mortality, averaging 3.5% over both the two and four week time periods. The significantly higher mortality in open plots can be directly related to predation. Lateral movement by clams from open plots is apparently not responsible for the occasionally large number of missing individuals, because losses of clams from fenced control plots were similar to losses from open plots. Clams that were missing may have been missed during sampling or may have been carried away by predators. Brachyuran crabs often move clams to their shelters for subsequent consumption (Boulding & Labarbera 1986), scavengers may carry clam remains away (Peterson 1982), and black drum swallow clams whole, crushing them with pharyngeal teeth (Simmons & Breuer 1962). The results indicate that missing clams almost certainly represent mortalities and that even though the experimental plots could potentially experience a large edge effect, manifested as emigration, this was not seen. If a large edge effect had been identified, our experiments would over-estimate mortality when compared with large commercial leases. The fencing study indicates that predators, rather than emigration, are responsible for missing clams.

TABLE 3.

Student-Newman-Keuls procedure for the effect of fencing and caging condition on percentage of *Mercenaria* lost following transplantation and relaying. Means with the same grouping are not significantly different.

Fence Condition	Mean % Missing	Grouping
Open	13.85	A
Fenced	12.63	A
Caged	1.83	B

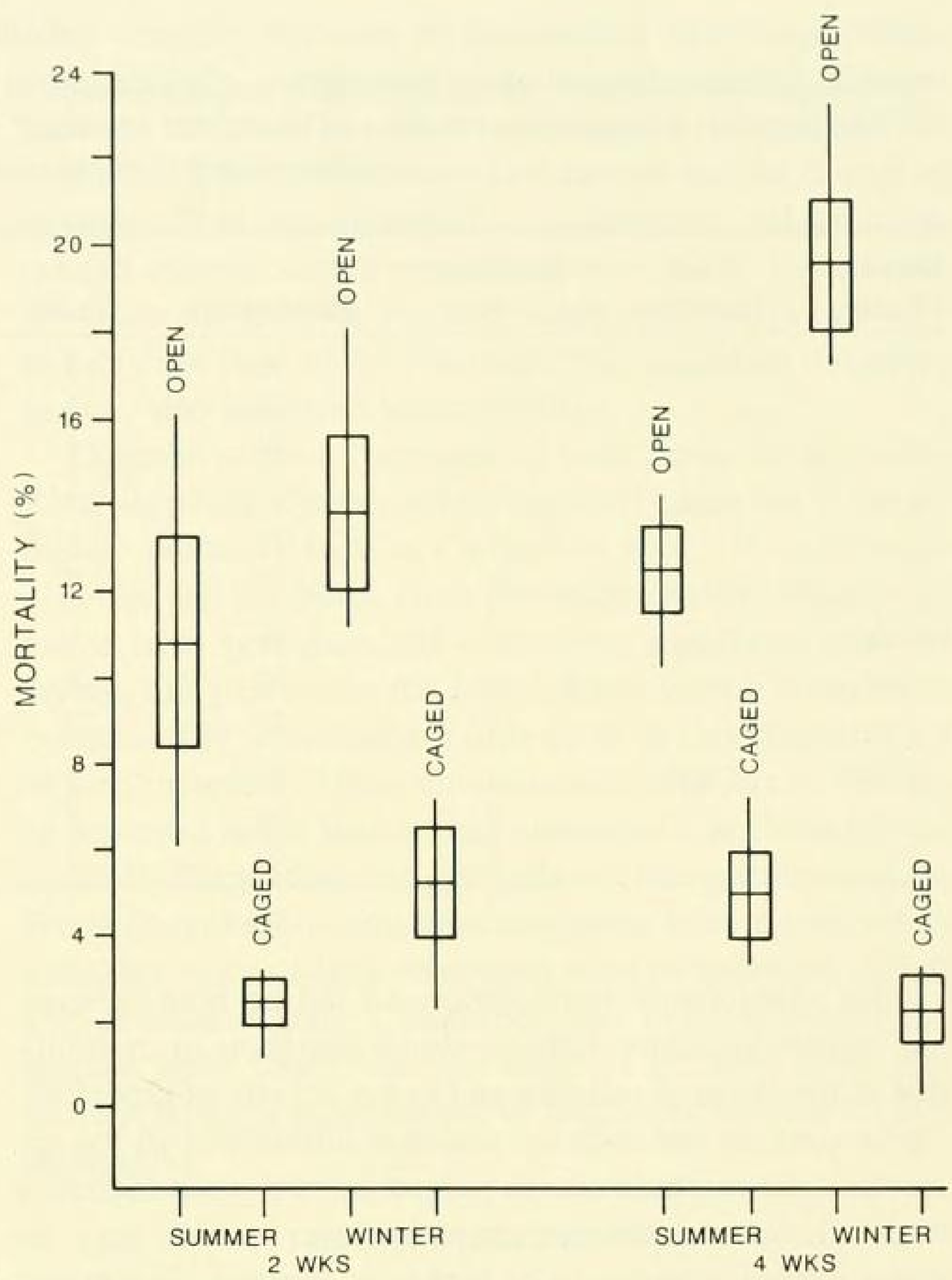

Figure 2. Mortality of Mercenaria spp. transplanted to caged plots and open plots during summer 1987 and winter 1988 and harvested after 2-week and 4-week intervals. Plots show means, ranges, and ± standard error (n = 3 for all treatments).

Although limited predation also occurred within the predator-exclusion plots, losses were minimal when compared with total mortality in open plots, indicating that the exclusion devices were effective barriers to predation.

Considerable information is available concerning losses of juvenile clams in field culture plots, but little information exists on mortality of clams of the sizes used in our experiments. For example, during a ten-month period in Alligator Harbor, Florida, Menzel et al. (1976) reported losses of 42.3% for clams in caged plots and 100% for clams in open plots for 7–10 mm SL *Mercenaria* spp. In an earlier seven-month study, Menzel and Sims (1962) reported mortalities of 5–18% in both open and caged plots containing clams 33–44 mm SL. These losses were attributed to predation by blue crabs, *Callinectes sapidus,* and whelks *Busycon sinistrum* (=*B. contrarium*) (Menzel & Sims 1962). The results of the present study indicate that loss rates of clams in the size range 50–75 mm SL are much lower than those observed for clams in smaller size classes. This agrees with previous observations, such as that of Arnold (1983), that predation rate of blue crabs generally decreases with increasing clam size.

TABLE 4.

Survivorship and associated sources of mortality among replicates of 100 *Mercenaria* spp. transplanted to caged and open plots, June 1987. Total mortality is divided into "Confirmed Dead" and "Missing" categories. Confirmed deaths are subdivided by specific cause: crab predation or undetermined reasons. All values are percentages.

Harvest Time	Cage Condition	Replicate No.	Survivorship	Dead	Crab Mortality	Undet. Mortality	Missing	Total Mortality	Mean Mortality
2 Wk	Open	1	90	5	2	3	5	10	10.67
		2	94	3	0	3	3	6	
		3	84	8	1	7	8	16	
2 Wk	Caged	1	97	2	2	0	1	3	2.33
		2	97	3	1	2	0	3	
		3	99	1	0	1	0	1	
4 Wk	Open	1	88	4	2	2	8	12	13.67
		2	82	8	0	8	10	18	
		3	89	3	1	2	8	11	
4 Wk	Caged	1	98	2	1	1	0	2	5.00
		2	93	5	1	4	2	7	
		3	94	2	1	1	4	6	

Our experiments were performed during both summer and winter to examine the seasonal variation in mortality due to the stress of relaying and to the activity of predators. These data do not indicate seasonal differences in the response time of predators (as judged by two-week mortality rates). Indeterminate mortality, however, which may be stress related, appears to be higher in summer. Symptoms of stress, including reduced growth, reduced reproductive activity and increased incidence of neoplasia, have been reported during the summer for hard clams from the Indian River lagoon (Arnold & Marelli, unpubl. data) (Hesselman et al. 1988).

Relay mortality is an important consideration in determining the relative economic efficiency of field- versus shore-based depuration. Clam losses during relaying are inevitable and acceptable as long as the losses, combined with the other associated costs of relaying (Holmsen & Stanislao 1966), do not outweigh the savings that would be realized by avoiding closed-cycle depuration. Estimates of the costs associated with relaying were obtained from five shellfish wholesalers and, using a modification of Holmsen and Stanislao's equation quantifying the cost of relaying, a range of estimates was produced for a variety of conditions (see Appendix). Under the most favorable conditions, relaying is economical only when reharvesting is very efficient (10% or less additional labor required to reharvest relayed clams), loss rates caused by relaying are very low (5% or less), and the dockside price of clams is low. Re-

TABLE 5.

Survivorship and associated sources of mortality among replicates of 100 *Mercenaria* spp. transplanted to caged and open plots, February 1987. Total mortality is divided into "Confirmed Dead" and "Missing" categories. Confirmed deaths are subdivided by specific cause: crab predation or undetermined reasons. All values are percentages.

Harvest Time	Cage Condition	Replicate No.	Survivorship	Dead	Crab Mortality	Undet. Mortality	Missing	Total Mortality	Mean Mortality
2 Wk	Open	1	90	4	0	4	6	10	12.33
		2	87	0	0	0	13	13	
		3	86	3	2	1	11	14	
2 Wk	Caged	1	97	2	0	2	1	3	4.67
		2	93	1	1	0	6	7	
		3	96	1	0	1	3	4	
4 Wk	Open	1	77	8	4	4	15	23	19.33
		2	83	7	2	5	10	17	
		3	82	1	1	0	17	18	
4 Wk	Caged	1	97	3	1	2	0	3	2.00
		2	97	2	1	1	1	3	
		3	100	0	0	0	0	0	

TABLE 6.

Analysis of variance for effects of cage conditions, time of harvest, and season on mortality of transplanted *Mercenaria* spp.

Source	df	SS	MS	F	p-value
Cage	1	661.50	661.50	75.60	$p < 0.0001$
Harvest Time	1	37.50	37.50	4.29	$p < 0.055$
Season	1	16.67	16.67	1.90	$p < 0.187$
Cage × Harvest Time	1	37.50	37.50	4.29	$p < 0.055$
Cage × Season	1	24.00	24.00	2.74	$p < 0.117$
Harvest Time × Season	1	0.67	0.67	0.08	$p < 0.786$
Cage × Harvest Time × Season	1	32.67	32.67	3.73	$p < 0.071$
Residual	16	140.00	8.75		
Total	23	950.50			

laying, as practiced in the Indian River lagoon, involves a team of 8 to 10 clammers moving clams to a shellfish lease, where they are simply dumped onto the lease bottom. After a minimum of 15 days the clams are reharvested by raking. With this method, neither efficiency level nor loss rate can be strictly controlled, although some shellfish dealers attempt to reduce losses by placing predator-exclusion mesh over the clams. The use of containerized relaying systems (e.g., Supan & Cake, 1982) would increase reharvest efficiency and decrease losses, but there are at least two problems associated with implementing containerized relaying in the Indian River lagoon. First, the additional cost of using predator-exclusion devices would initially increase the cost of field-based depuration relative to the shore-based alternative. Second, Florida law currently prohibits the use of any structure which extends more than 6″ above the bottom, which would make it very difficult to use containerized relay systems. Despite the legal aspects, if this technology can be demonstrated to be both efficient and compatible with use plans for the Indian River lagoon, then serious consideration should be given to using some form of containerized relay system. One example of this technology is currently under development by the Harbor Branch Oceanographic Institution, Division of Applied Biology.

In addition to the added cost of relaying, leaseholders must consider the costs of maintaining their leases; these costs include lease rental and the maintenance of lease markers. Other factors that argue against relaying are the two-week delay between the clam harvest and the receipt of payment, and the possibility of additional delays when rainfall events cause temporary closure of the lagoon area in which the lease is located. Additional delays not only reduce cash flow to the clammers but, according to our research, also increase clam mortality.

Concentrations of unprotected hard clams in the Indian River lagoon are strongly and negatively affected by large, mobile predators such as *Callinectes* spp.,[3] *Menippe mercenaria,* and the black drum *Pogonias cromis.* Because of losses from predation and other costs associated with relaying, this practice in the Indian River lagoon is currently economically advantageous only under a very restricted set of circumstances. These circumstances will rarely, if ever, be achieved in the lagoon, and additional complications are posed by fluctuating and generally declining water quality. Predator exclusion containers may make relaying more feasible, but costs of such containers must be balanced against any economic gain. Conditions that exist in other geographic areas throughout the range of the hard clam may make relaying a more attractive alternative to closed-cycle depuration.

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[3]Three species of *Callinectes* occur in the Indian River lagoon (Gore 1977), and we did not distinguish among them.

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APPENDIX

Estimates of the added costs of field depuration and closed-cycle depuration. Original equation from Holmsen and Stanislao (1966).

Variable	Description	Estimate
Y	Added cost of relaying per bushel	
Q	No. bushels harvested per day (8-person relay team)	34–40
C	Cost of boat operation per day (relay team)	$160
P	Dockside price of bushel	$30–75
D	Efficiency of relaying as opposed to harvesting (=time spent reharvesting clams as a % of original harvest time)	30%
N	% loss due to relaying	11.5–16.5%
O	Cost of bonded observer	$60

The equation for the added cost of depuration is

$$Y = \frac{(P)\,(Q)\,(N) + (C + (Q)\,(P) + O)\,D}{Q}$$

Holmsen and Stanislao (1966) did not include the (Q × P × D) and the (O × D) terms. The (Q × P × D) term is included because time spent reharvesting field-depurated clams is time taken away from harvesting open-water clams and thus represents a loss of efficiency. The (O × D) term is added because an observer is needed when relaying to a lease or to closed-cycle depuration, and an observer must also be hired when clams are reharvested from the shellfish lease. Closed-cycle depuration costs can be estimated with knowledge of the following two terms: CC = cost per clam for depuration (varies between $0.02 and $0.03), and B = number of clams per bushel. The number of clams per bushel (B) varies inversely with the size of the clams being harvested, and averages 200 to 350 for Indian River clams. Closed-cycle depuration costs using the range of variables are as follows:

CC	B	Cost of Closed-Cycle Depuration (per bushel)
$0.02	200	$4.00
0.02	250	5.00
0.02	300	6.00
0.02	350	7.00
0.025	200	5.00
0.025	250	6.25
0.025	300	7.50
0.025	350	8.75
0.03	200	6.00
0.03	250	7.50
0.03	300	9.00
0.03	350	10.50

Comparing these estimates to estimates of Y based on a range of levels of the variables indicates that relaying is theoretically not profitable as practiced in the Indian River unless certain variables are held at what we consider to be unreasonably low values. Cost of relaying declines when Q (number of bushels harvested) increases and declines when all other variables decrease. The most critical variables in determining the estimated costs are N (% loss due to relaying), D (efficiency of relaying), and P (dockside price per bushel). In the following table, the variables C, O, and Q are set at conservative and realistic levels and the variables P, D, and N are varied.

C	P	D	O	Q	N	Y	Depuration Cost	Savings/ Loss	CC	B
120	50	0.5	60	37.5	0.115	33.15	6.25	−26.9	0.025	250
120	37.5	0.5	60	37.5	0.115	25.46	6.25	−19.212	0.025	250
120	25	0.5	60	37.5	0.115	17.77	6.25	−11.525	0.025	250
120	50	0.4	60	37.5	0.115	27.67	6.25	−21.42	0.025	250
120	37.5	0.4	60	37.5	0.115	21.23	6.25	−14.982	0.025	250
120	25	0.4	60	37.5	0.115	14.79	6.25	−8.545	0.025	250
120	50	0.3	60	37.5	0.115	22.19	6.25	−15.94	0.025	250
120	37.5	0.3	60	37.5	0.115	17.00	6.25	−10.752	0.025	250
120	25	0.3	60	37.5	0.115	11.81	6.25	−5.565	0.025	250
120	50	0.2	60	37.5	0.115	16.71	6.25	−10.46	0.025	250
120	37.5	0.2	60	37.5	0.115	12.77	6.25	−6.5225	0.025	250
120	25	0.2	60	37.5	0.115	8.835	6.25	−2.585	0.025	250
120	50	0.1	60	37.5	0.115	11.23	6.25	−4.98	0.025	250
120	37.5	0.1	60	37.5	0.115	8.542	6.25	−2.2925	0.025	250
120	25	0.1	60	37.5	0.115	5.855	6.25	0.395	0.025	250
120	50	0.5	60	37.5	0.05	29.9	6.25	−23.65	0.025	250
120	37.5	0.5	60	37.5	0.05	23.02	6.25	−16.775	0.025	250
120	25	0.5	60	37.5	0.05	16.15	6.25	−9.9	0.025	250
120	50	0.4	60	37.5	0.05	24.42	6.25	−18.17	0.025	250
120	37.5	0.4	60	37.5	0.05	18.79	6.25	−12.545	0.025	250
120	25	0.4	60	37.5	0.05	13.17	6.25	−6.92	0.025	250
120	50	0.3	60	37.5	0.05	18.94	6.25	−12.69	0.025	250
120	37.5	0.3	60	37.5	0.05	14.56	6.25	−8.315	0.025	250
120	25	0.3	60	37.5	0.05	10.19	6.25	−3.94	0.025	250
120	50	0.2	60	37.5	0.05	13.46	6.25	−7.21	0.025	250
120	37.5	0.2	60	37.5	0.05	10.33	6.25	−4.085	0.025	250
120	25	0.2	60	37.5	0.05	7.21	6.25	−0.96	0.025	250
120	50	0.1	60	37.5	0.05	7.98	6.25	−1.73	0.025	250
120	37.5	0.1	60	37.5	0.05	6.105	6.25	0.145	0.025	250
120	25	0.1	60	37.5	0.05	4.23	6.25	2.02	0.025	250

This table clearly shows that when comparing costs of relaying with the costs of land-based depuration, relaying is only rarely profitable. In fact, there are only three cases in which relaying would be profitable, and the maximum benefit per 8-person relay team would total $82.50, or $10.31 per team member. We feel that in this scenario, an efficiency value of 10% and a loss value of 5% are unrealistically low, and we conclude that relaying as currently practiced in the Indian River lagoon is not profitable.