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BIOLOGICAL CONTROL OF CRAB PREDATION ON HARD CLAMS *MERCENARIA MERCENARIA* (LINNAEUS, 1758) BY THE TOADFISH *OPSANUS TAU* (LINNAEUS) IN TRAY CULTURES¹

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ABSTRACT Oyster toadfish *Opsanus tau* (Linne) were tested as biological controls of crab predation on juvenile hard clams *Mercenaria mercenaria* (Linne) in trays with crushed stone aggregate. Clam survival after 34 weeks was 69.5% in the presence of toadfish and 2.3% in trays without toadfish. Toadfish reduced the total number of crabs (mud crabs and blue crabs). Crabs in trays with toadfish present had smaller carapace widths.

KEY WORDS: predation, toadfish, *Opsanus*, crabs, hard clams, *Mercenaria*, tray culture

INTRODUCTION

A major factor limiting production of juvenile hard clams cultured in the field is crab predation (Whetstone and Eversole 1978, Jory et al. 1984, Gibbons and Blogoslawski 1989). Clam growers attempt to exclude predators from field cultured clams by using rafts, trays, cages, and nets (Castagna and Kraeuter 1981, Castagna 1983, Jory et al. 1984). Increasing the chances of high survival rate in clam culture requires the use of seed clams larger than 6 mm shell height (SH) (Kraeuter and Castagna 1985). Large seed is not only more costly than smaller seed, but is often in short supply. The development of a viable method for using smaller seed in field culture is needed.

Walker (1984) suggested that survival of seed less than 18 mm in shell length depended on frequent removal of newly metamorphosed crabs from within cages. Field growout structures often attract or even trap juvenile crabs that pass through netted enclosures and grow to sizes large enough to cause significant mortality on smaller clams. Both mud crabs and blue crabs can prey on clams with SH about one third the carapace width of the crabs and may have feeding rates of 136 and 308 clams/crab/day, respectively (Carriker 1961, Castagna and Kraeuter 1981, Gibbons 1984).

Successful use of small seed clams, *Mercenaria mercenaria* (Linne), (<4 mm SH) in field cultures has been achieved by Gibbons and Castagna (1985). They found that oyster toadfish *Opsanus tau* (Linne) were effective in reducing crab predation on clams planted in the bottom under crushed stone aggregate. Survival after 6 weeks was about 50% in plots containing a single toadfish and 2% without toadfish. Flagg and Malouf (1983) found higher clam survival in uncovered trays that were found to have toadfish living in close proximity. The oyster toadfish, *Opsanus tau*, is a nonmigratory species whose diet consists primarily

of crabs (Gudger 1910, Schwartz and Dutcher 1963, McDermott 1964, Wilson et al. 1982). Gibbons and Castagna (1985) found toadfish to be a significant predator of mud crabs (Decapoda: Xanthidae) and the portunid blue crab, *Callinectes sapidus* Rathbun. This study examined the survival of juvenile hard clams as influenced by toadfish presence in trays of small cultured clam seed.

MATERIALS AND METHODS

The experiment was conducted from August 1987 to April 1988 in Bradfords Bay near Wachapreague, VA (U.S.A.). Juvenile hard clams reared at the Wachapreague Laboratory of the Virginia Institute of Marine Science were sieved through a 3 mm mesh screen, caught on a 2 mm mesh screen and divided into 10 groups of 6400 each. A random sample of 100 was photocopied for shell height measurements (hinge to lip) (Haines 1973). Toadfish were collected locally and had total lengths (TL) of 216 ± 15.5 mm (mean \pm standard deviation, $n = 5$). Ten trays, $200 \times 100 \times 9$ cm (inside dimensions) with wood sides were used. The bottoms were fitted with 1.4 mm mesh fiberglass screen over heavier 13 mm mesh plastic screen bottoms. Trays were filled with crushed stone aggregate 2.5 cm deep and covered with 6 mm plastic mesh.

Trays were deployed subtidally (depth at mean low water was approximately 60 cm) on August 19, 1987. Each tray received 6400 clams ($3200/m^2$) and 5 of the trays received one toadfish each. Trays were sampled on October 6 (48 days) and November 16 (89 days), 1987, and April 19, 1988 (244 days) by taking ten 71.5 mm dia. randomly located core samples in each. The number of live clams per sample was recorded and clams from each tray were photocopied for shell height (SH) measurement. The number and carapace width (CW) of crabs collected in samples were also recorded. On the October sampling, the toadfish was missing from a tray with a torn net. The net was repaired and another toadfish 193 TL was added. Fouling was cleared from the nets at each sampling. At the final sam-

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pling in April, each tray was thoroughly examined for crabs, which were measured and identified. A final estimate of clam survival was made by determining the total volume of clams and aggregate per tray, taking two random samples of one liter each, and counting the number of live clams per liter.

Prior to statistical testing all data was log transformed which fixed heteroscedastic variances. The number of live clams per core sample was transformed to $\log(x + 1)$. The transformed data were compared in a three-way nested analysis of variance (ANOVA) with trays nested within toadfish treatment and time of sample as factors. Clam shell heights were transformed to $\log x$ and compared between sampling times with a one-way ANOVA. Differences in mean shell height were further analysed with the new Duncan's multiple range test (Steel and Torrie 1960). Differences in final shell heights of clams between trays and treatments were compared with a two-way ANOVA. The numbers of mud crabs, blue crabs, and total crabs collected at the end of the study were also log transformed and one-way ANOVA were used to test for differences between treatments. A log transformation was also applied to the carapace widths of mud crabs and blue crabs from the final sampling; one-way ANOVA were used to compare treatments.

RESULTS

Clam survival in the trays as determined by core sampling after 244 days was 69.5% in the presence of toadfish compared to 2.3% when toadfish were absent (Table 1). Using the two-liter subsample method, estimated final clam survival in the presence of toadfish was 69.9% and 2.4% when toadfish were absent. There were significant differences in toadfish presence ($F = 93.0$, d.f. = 1, $p < 0.001$) and time of sample ($F = 17.8$, d.f. = 2, $p < 0.001$). Differences within treatment trays were not significant ($F = 2.0$, d.f. = 4, $p = 0.09$). Shell heights of clams sampled in October, November, and April were not significantly different from each other but were significantly different from initial shell height measurements ($p < 0.05$) (Table 2). Slow clam growth was due to cold water temper-

atures during the winter and reduced water circulation within trays caused by fouling of nets with red algae, which was removed at October and November samplings. There were no significant differences in shell heights at final sampling due to toadfish presence ($F = 0.00$, d.f. = 1), tray ($F = 0.87$, d.f. = 4) or toadfish presence-tray interactions ($F = 2.12$, d.f. = 4, $p = 0.076$).

Two crab species were found in the trays, the mud crab, *Neopanope sayi* (Smith), and the blue crab, *C. sapidus*. There was no significant difference ($F = 1.3$, d.f. = 1, $p = 0.28$) in the mean number of mud crabs found per tray, although the mean number in the trays containing toadfish was lower (15.8/tray) than in trays without toadfish (22.0/tray) (Table 3). There were significantly fewer numbers of blue crabs ($F = 19.3$, d.f. = 1, $p = 0.002$) and total crabs ($F = 9.8$, d.f. = 1, $p = 0.01$) per tray in the presence of toadfish (Table 3). Significantly smaller carapace widths of mud crabs ($F = 4.2$, d.f. = 1, $p = 0.04$) and blue crabs ($F = 9.6$, d.f. = 1, $p = 0.003$) were found in those trays with toadfish (Table 4). Blue crabs of 38.4 mm CW and mud crabs of 18.4 mm CW were present in trays after 48 and 89 days, respectively (Table 5).

Toadfish appeared healthy at October and November samplings. The tray missing a toadfish at the October sampling received a new toadfish. This did not appear to affect the results. All toadfish were found dead at the April sampling, which probably may have been caused by exposure to the cold winter surface water temperatures. The light siltation found in all trays allowed for free movement of the toadfish, yet offered no protection from the cold water.

DISCUSSION

Toadfish effectively controlled crab predation on juvenile hard clams starting at 3.6 mm SH for more than 8 months in tray cultures. After almost 7 weeks estimated clam survival was 100% with toadfish present and 46.9% without toadfish. Gibbons and Castagna (1985) found clam survival of 49.2% with toadfish and 1.6% without toadfish using bottom planting in crushed stone aggregate with 25 mm mesh pens instead of trays with 6 mm mesh net covers used in the present study. Further, the toadfish in the pre-

TABLE 1.

Mean number of live hard clams found per core sample with 95% confidence limits ($n = 5$), and estimated percent survival at October, November, and April sampling periods for trays with toadfish present or absent.

Sample date	Toadfish			
	Present		Absent	
	Mean \pm C. L.	% Survival	Mean \pm C. L.	% Survival
October	12.9 \pm 2.4	100.8	6.0 \pm 3.2	46.9
November	6.8 \pm 4.9	53.1	1.2 \pm 1.2	9.4
April	8.9 \pm 2.9	69.5	0.3 \pm 0.2	2.3

TABLE 2.

Mean shell heights (SH) in mm with 95% confidence limits (n = 100) for hard clams sampled in August, October, November, and April.

Sample date	SH \pm C. L. (mm)
August	3.57 \pm 0.02*
October	4.96 \pm 0.17
November	5.52 \pm 0.19
April	6.14 \pm 0.29

* Significantly smaller than rest (p = 0.05).

vious study patrolled half the area of this study. A laboratory study by Bisker et al. (in preparation) reported only a slight decrease in blue crab predation on clams in the presence of toadfish after two days, but used crabs of 84.5 mm CW which were three to four times larger than those found in the field trays. Blue crabs of 84.5 mm CW can pass through nets of 25 mm mesh but not through those of 6 mm mesh, and may prey on juvenile clams at a rate of 307/day (Carriker 1959, Bisker and Castagna 1987). Use of the smaller 6 mm mesh netting eliminated the larger crabs with higher predation rates, therefore enhancing the control of crab predation by the toadfish.

There was a noticeable reduction in survival of those clams in trays with toadfish between the October (100%) and the November (53.1%) samples. This reduced survival may have been caused by an increase in the number of mud crabs and blue crabs large enough to prey on the clams. Water temperatures were still warm enough during this period for active crab predation to occur. Sample error may have contributed to the lower clam survival found in the November sample as the final sampling had 16.4% higher survival.

Labor required for removal of crabs from trays reported by Walker (1984) was not required in our study as toadfish reduced crab numbers and sizes. Toadfish also may reduce crab feeding efficiencies by injuring crabs or by invoking increased defensive behavior in the presence of toadfish. Blue crabs have demonstrated avoidance behavior in the

TABLE 3.

Mean number of mud crabs and blue crabs found per tray with 95% confidence limits (n = 5) at final sample period in April for trays with toadfish present or absent.

	Toadfish	
	Present	Absent
	Mean \pm C. L.	Mean \pm C. L.
Mud crabs	15.8 \pm 2.7	22.0 \pm 10.5
Blue crabs	1.2 \pm 1.6	8.0 \pm 3.7
Total crabs	17.0 \pm 3.8	30.0 \pm 12.0

TABLE 4.

Mean carapace width (CW) in mm with 95% confidence limits for mud crabs and blue crabs found in trays at final sample period in April for trays with toadfish present or absent.

	Toadfish			
	Present		Absent	
	Mean \pm C. L.	N	Mean \pm C. L.	N
Mud crab	11.7 \pm 1.1	79	12.8 \pm 0.8	110
Blue crab	19.6 \pm 2.6	6	28.5 \pm 2.6	40

presence of toadfish, and some even crawl out of the water to escape (Bisker et al., in prep.).

Toadfish reduced the number of blue crabs more effectively than mud crabs. This may be due to the more obvious behavior of the blue crab making it easier to discover. Blue crabs have difficulty burrowing in the crushed stone substrate and are more vulnerable (Bisker et al., in prep.). Toadfish predator-prey size ratios (CW/TL) are 0.10 for mud crabs and 0.32 for blue crabs (Bisker et al., in prep.). All crabs found in the trays were sizes that could be preyed on by the toadfish used.

Neopanope sayi, the mud crab species found in the trays, can devour as many as 134 clams/day and are found as dense as 54 crabs/m² (MacKenzie 1977, Gibbons 1984). Blue crabs can eat as many as 307 clams/day but densities are far less, 13 crabs/m², perhaps as a result of their antagonistic territorial behavior (Carriker 1954, Larson 1974). Clam mortality in the trays without toadfish averaged 36 clams/day/m² for the first 48 days, and averaged about 13 clams/day/m² for the entire study. Gibbons and Castagna (1985) found clam mortality rates of about 75 dead clams/day/m² in cages without toadfish after 42 days. Crab densities in trays without toadfish were 11 crabs/m² for mud crabs and 4 blue crabs/m² after 8 months. Crab densities in trays containing toadfish were 7.9/m² for mud crabs and 0.6/m² for blue crabs. The small density decrease of 3.1 mud crabs/m² and 3.4 blue crabs/m² in trays with toadfish allowed for 96.8% better clam survival after 8 months.

Mean clam shell heights in the present study increased 1.4 mm after the first 48 days. Gibbons and Castagna (1985) found an increase of 3.5 mm mean shell height after 42 days from clams held on the bottom in cages of 2.5 mm mesh during a similar time of year. The slower clam growth found in the present study was probably caused by reduced water circulation in the trays. The solid wood tray sides and fouling of the 6 mm mesh covers by algae slowed the exchange of water within the trays and thus limited food for the clams.

Although all toadfish were dead at the end of the experiment, they are generally hardy fish and have survived overwintering in other trays that were held in deeper water (per-

TABLE 5.

Carapace widths in mm of mud crabs and blue crabs collected in core samples for each sample period from trays with toadfish present or absent.

Sample period	Toadfish			
	Present		Absent	
	Mud crab	Blue crab	Mud crab	Blue crab
October		7.2 9.6		38.4
November	18.4 6.1 5.2	12.0	4.4	43.2 7.9
April	11.7 9.6		15.2 15.8	22.0 29.8

sonal observation). Toadfish are easy to capture and handle and require little attention during use as a biological control for crabs in clam trays. Results of this study clearly show that use of toadfish is beneficial when used to protect small hard clams less than 10 mm SH, allowing the use of smaller and less expensive clam seed in grow-out systems.

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