Abstract.—Stock enhancement with hatchery-reared juvenile queen conch, *Strombus gigas* L., has been suggested as a means to rehabilitate overfished populations in Florida and the Caribbean region. A 15-month field experiment was conducted in the Bahamas to compare the survival, growth, morphology, and behavior of hatchery-reared and wild juvenile conch (85–120 mm shell length). Two experimental sites were established. Site C1 contained a resident conch population whereas few conch occurred naturally at site C2. Survival was higher for wild conch than for hatchery-reared conch. After 7 months, 28% of the original wild conch were recovered compared with only 9% of the hatchery-reared conch. Thin shells, short spines, and low burial frequency in hatchery-reared conch may have caused them to be more vulnerable to predators. In a tethering experiment, about twice as many hatchery conch were killed as wild conch, but the difference was not significant inside enclosures. Survivorship was higher at the site with resident juveniles, probably because of density-dependent protection from predation. After a period of high mortality in free-ranging conch during the first two months, tag recovery curves for both stock types reached a plateau. Also, near the end of the study, shell characteristics of wild and hatchery conch were identical as was survivorship. Analysis of movement patterns indicated that both stock types moved toward the natural population center. Although survivorship was higher at the site with resident conch, growth rates for both stock types were often lower at this site. Algal foods may have been more abundant at the site without conch because of lower grazing pressure. Athough highest mean daily growth occurred at 1.0 conch·m^{-2}, growth rates of conch enclosed at 0.5, 1.0, and 2.5 individuals·m^{-2} were not significantly different in most cases. Growth rates were higher for wild conch than for hatchery conch. In summer, free-ranging and tethered wild conch grew twice as fast as hatchery-reared conch. Success in rehabilitating depleted queen conch populations will require the release of high quality, hatchery-reared juveniles in large numbers in appropriate habitats.

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Experimental outplanting of juvenile queen conch, *Strombus gigas*: comparison of wild and hatchery-reared stocks

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Widespread depletion of natural fishery stocks, particularly in inshore coastal and estuarine habitats, has resulted in increasing interest in enhancement and restoration of wild populations through releases of hatchery-reared individuals. Among the molluscs, relatively sedentary bivalves such as oysters, *Crassostrea* spp. (Burrell et al., 1981; Goodwin[1]), clams, *Mercenaria mercenaria* (Flagg and Malouf, 1983), mussels, *Mytilus edulis* (Dare and Edwards, 1976), and giant clams, *Tridacna* spp. (Heslinga et al., 1984; Heslinga and Watson, 1985) have been restocked most successfully. Experimental reseeding of scallops, *Argopecten* and *Patinopecten* spp. (Saito, 1984; Aoyama, 1989; Tettelbach and Wenczel, 1991) and abalone, *Haliotis* spp. (Kojima, 1981; Saito, 1984; Uki, 1984; Searcy and Salas, 1985; Tegner and Butler,1985; Tong et al., 1987; Ebert, 1989; Emmett and Jamieson, 1989) also show promise.

Queen conch, *Strombus gigas*, is one of the most important fishery species in the Caribbean region (Brownell and Stevely, 1981; Berg and Olsen, 1989), with an estimated annual value of 30 million U.S. dollars (Appeldoorn and Rodriquez, 1993). Heavy fishing for queen conch in shallow water habitats has resulted in a decline of this species throughout most of its biogeographic range (Appeldoorn et al.,1987; Appeldoorn and Rodriguez, 1993), and the U.S. fishery has been closed completely since 1986 (Berg and Olsen, 1989). Mariculture has been suggested as a way to rehabilitate queen conch populations (Berg, 1976; Siddall, 1984a; Davis et al., 1987), and research efforts during the past two decades have made it possible to culture large numbers of juvenile conch for stock enhancement (Brownell, 1977; Ballantine and Appeldoorn, 1983; Hensen, 1983; Laughlin and Weil, 1983; Cruz, 1986; Davis et al., 1987; Heyman et al., 1989; Creswell,1993; Davis, 1993). Unfortunately, field outplants of hatchery-reared stock have met with little success because of very high mortality (Appeldoorn and Ballantine, 1983; Laughlin and Weil, 1983; Appeldoorn, 1985; Marshall et al., 1993; Dalton, 1993). Also, little is known about the relative viability of wild and hatchery-reared conch.

This study uses a large-scale outplant experiment, together with enclosure and tether experiments, to compare the survival, growth, morphology, and behavior of hatchery-reared and wild juvenile conch released into a well-studied nursery

[1] Goodwin, W.F. 1981 Use of seed oysters to supplement oyster production in southern North Carolina. Report, North Carolina Division of Marine Fisheries, NCDMF - Project - 2/314-R, 109 p.

site (Stoner and Sandt, 1991, 1992). This research provides further insight into the potential for using cultured conch in a stock enhancement program, and elucidates possible limitations.

Methods and materials

Site description

During the 15–month period from March 1990 to May 1991, all field outplant, enclosure, and tether experiments were carried out at two different sites designated C1 and C2 (Fig. 1). The study sites, each a 100–m square area delineated by buoys, were located 0.8 km west of Children's Bay Cay and 5.0 km southeast of the Caribbean Marine Research Center field station on Lee Stocking Island, in the southern Exuma Cays, Bahamas (lat. 23°44.5'N, long. 76°04.4'W) (Fig. 2). A shallow sand bank is to the southwest. The two sites are in a homogeneous seagrass meadow of *Thalassia testudinum* with moderate shoot density (500–700 shoots·m^{-2}) in 3.2 m depth. Tidal currents run northwest (flood) and southeast (ebb) at velocities to 50 cm·sec^{-1} with a tidal range of approximately 1.0 m. Clear water from the Exuma Sound flows over the sites on flood tides, resulting in high underwater visibility that facilitated field experiments and recovery of tagged conch.

Site C1 was established within a well-studied queen conch nursery area that has carried as many as 500,000 individuals in densities between 0.5 and 2.0 conch·m^{-2} since at least 1984 (Wicklund et al., 1991; Stoner et al. 1993, unpubl. data). Site C1 has been the location of numerous investigations on conch mass migration (Stoner et al., 1988; Stoner 1989a), distribution (Stoner and Waite, 1990), and diet (Stoner and Waite, 1991).

Site C2 was approximately 0.3 km to the southeast of site C1 and had very few juvenile conch (< 0.05 conch·m^{-2}). In 1988, small-scale transplants in enclosures showed that young conch survived and grew at nearly identical rates at sites C1 and C2 despite the absence of wild conch at the latter (Stoner and Sandt, 1992). This suggested that certain unpopulated areas of the extensive seagrass meadows in the Exuma Cays could support outplanted conch stocks.

Density estimates were obtained by counting the conch (tagged and untagged) in as many as 20 haphazardly placed circles of 4-m radius at each site at five different times during the experiment. The purpose of these estimates was to assess the natural population of conch prior to the transplant, to exam-

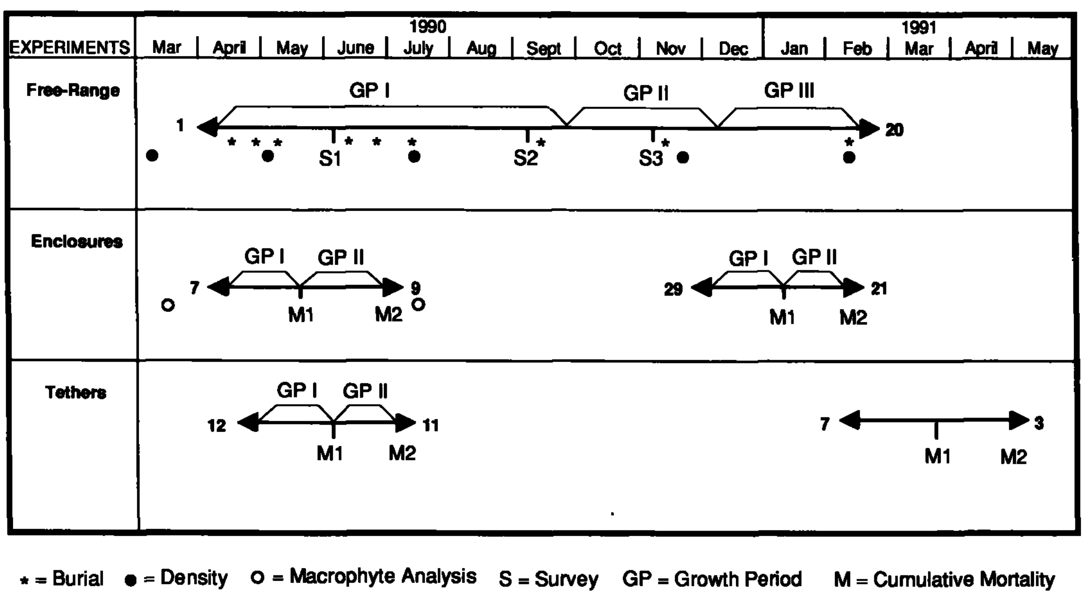

Figure 1

Calendar of free-ranging, enclosure, and tether experiments; showing duration of experiments, data collection points, and time periods for growth and mortality of queen conch, *Strombus gigas*. The total study period extended from March 1990 to May 1991. See text for descriptions of the measurements and experiments.

ine the density of conch at the end of the experiment, and to observe movements by the population. On each date up to 100 conch were measured for shell length (apex to siphonal canal).

Seawater temperature for the study site was recorded with a Ryan Temp Mentor placed on the bottom between sites C1 and C2. Temperature was recorded (+ 0.2°C) every 30 minutes, and seven-day mean temperatures were calculated for plotting (Fig. 3).

Experimental animals

Approximately 6,000 wild and 6,000 hatchery-reared conch were used in the experiments described below. Wild conch were collected from the Children's Bay Cay nursery site (C1); all were between 85 and 120 mm shell length (SL). Hatchery-reared conch were purchased from Tradewind Industries, Ltd. (Caicos Conch Farm) in Providenciales, Turks, and Caicos Islands. These conch originated from 12 egg masses collected near Providenciales in the summer of 1988. The larvae were fed with Caicos *Isochrysis* and postlarvae with flocculated *Chaetoceras gracilis* and blended *Enteromorpha* sp. (Davis et al., 1992). Between December 1988 and March 1989, 50-mm juveniles were transplanted to a protected nursery habitat near the hatchery (Davis and Dalton, 1991).

Between 26 and 29 March 1990, 6,000 hatchery-reared conch comparable in size to the 1+ year class conch native to Children's Bay Cay nursery (85–120 mm SL)(Table 1) were collected from the grow-out area and held in two 8 × 8 m holding pens. On the morning of 30 March the conch were loaded into 32 large burlap sacks wrapped in plastic bags and transported via cargo plane to Lee Stocking Island. The conch were kept cool and moist during the 7-hour period out of the water. Upon arrival, conch were immediately taken to either site C1 or C2. The plastic was removed and the burlap bags were placed on the bottom of the respective sites. On 31 March they were released into two temporary pens (10 m^2) already constructed at each of the study sites. All hatchery-reared conch were tagged and measured over the next 10 days. Wild conch were tagged and placed in temporary pens during a 10-day period prior to the arrival of the hatchery-reared conch.

All conch were marked with orange spaghetti tags (Floy Manufacturing Co.) tied around the spire, and total shell length was measured to the nearest millimeter (±1 mm) with calipers. Tags were both letter coded and numbered so that conch type and release site could be identified immediately in the field.

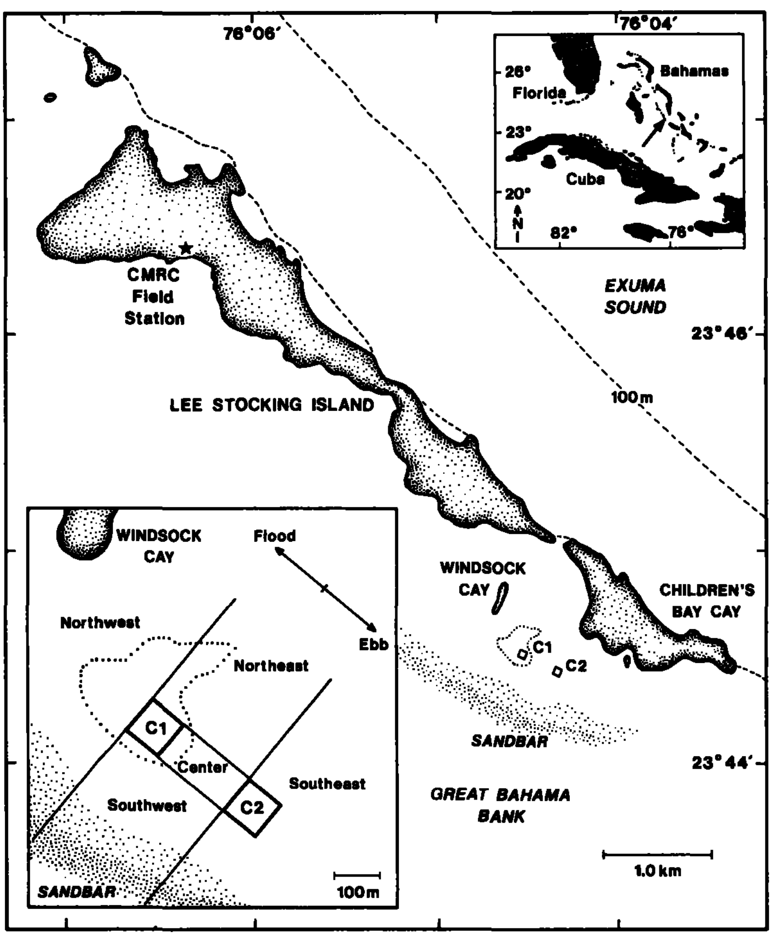

Figure 2

Map of Lee Stocking Island and Children's Bay Cay in the southern Exuma Cays, Bahamas. Study sites C1 and C2 are shown as squares, the dotted line around C1 represents the approximate boundaries of the natural queen conch, *Strombus gigas*, population in July 1990. The lower insert shows the geographic zones surveyed during each tag recovery.

Free-ranging experiment

Hatchery-reared and wild tagged conch were haphazardly released throughout each of the two 100 m × 100 m experimental sites (C1 and C2) to examine survivorship, growth, morphology, and behavior of free-ranging juveniles between 1 April 1990 and 20 February 1991. The size ranges for hatchery and wild conch released at site C1 were 80–117 mm SL (mean=102, SD=8, n=2,552) and 85–117 mm SL (mean=100, SD=7, n=2,543), respectively. For site C2, the size ranges for hatchery and wild conch were 80–117 mm SL (mean=101, SD=8, n=2,540) and 83–117 mm SL (mean=101, SD=6, n =2,490), respectively.

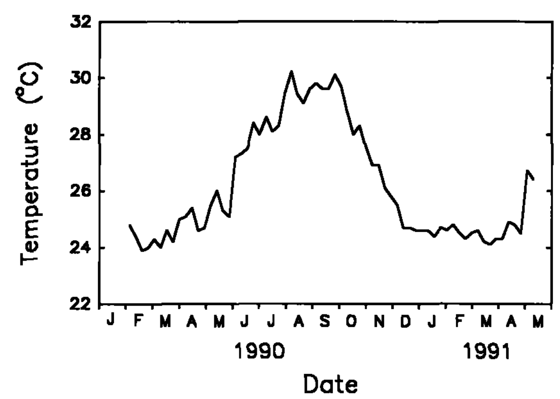

Figure 3

Bottom-water temperature recorded between sites C1 and C2, during the study period. Seven-day averages for recordings made every 30 minutes are plotted.

Table 1

Density of juvenile queen conch (*Strombus gigas*) in two field sites (C1 and C2) prior to the release of tagged conch (2 Mar. 1990), during the release experiment, and at the end of the experiment (21 Feb. 1991). Density was measured by counting conch, including tagged conch, in up to 20 randomly-selected 4-m diameter circles (50 m^2) at each site. Mean shell length for up to 100 individuals was measured for conch found in each survey. Values are mean ± SD (n).

Date	Number of plots	Density (mm)	Shell length (no./m^2)
Site C1			
2 Mar 90	20	0.26 + 0.12	105 + 14 (100)
2 May 90	20	1.27 + 1.01	n/a
16 Jul 90	20	0.66 + 0.31	111 + 12 (100)
27 Nov 90	5	0.22 + 0.12	113 + 16 (55)
21 Feb 91	6	0.19 + 0.19	129 + 13 (56)
Site C2			
2 Mar 90	20	0.01 + 0.01	99 + 14 (9)
2 May 90	20	0.03 + 0.03	n/a
16 Jul 90	20	0.62 + 0.74	119 + 10 (100)

Tag recovery Tag recapture surveys were conducted in June, September, and November 1990, to provide a relative index of survivorship over time and space. Searches encompassed the transplant sites, the zone between the sites, and adjacent seagrass and sand habitats. The search area was sectioned arbitrarily (see insert, Fig. 2), and several divers using snorkel or SCUBA gear drifted repeatedly side by side over the area using the flood tidal current for transport. Conch location was recorded by section, and searches continued until no additional conch were found. After each survey, all recaptured conch were returned to their original transplant sites (C1 or C2). Because very few hatchery-reared conch remained alive in February 1991, collections were made for shell growth and morphology, but the complete survey was not conducted.

Tag recovery does not measure absolute survivorship because of potential emigration from the study site and possible inefficiency in finding tagged animals; however, the search effort was intensive, and clear water (usually >10 m horizontal visibility) facilitated the efficiency of the searches. In two blind tests 87 and 92% of 200 uniquely tagged conch were recovered by using standard search procedure (unpubl. data). The surveys were conducted over periods from 7 to 20 days depending upon the number of divers available. Because of known limitations, tag recovery data were used as a relative indicator of survivorship in the two stock types and two study sites.

Growth Seasonal growth rates (mm·day^{-1}) were determined for three periods: summer (April to September 1990), fall (September to November 1990), and winter (November 1990 to February 1991) by comparing shell lengths of individual, tagged conch at the beginning and end of the survey periods.

Shell morphology At the beginning (1 April 1990) and end of the experiment (20 February 1991), representative samples of at least 30 hatchery-reared and 30 wild conch (collected alive) were measured for shell length and width, and shell and tissue weight. Maximum shell width was the distance between the last complete spine formed near the shell aperture and the spine on the opposite side of the shell. Total weight of the shell and soft tissue (live weight) was recorded to the nearest 0.01 g. After freezing and subsequent thawing, the soft tissue of the animal was extracted, lightly blotted, and weighed. Weights of the clean, air-dried shells were also recorded.

Behavior Nine times during the study, observations on burial behavior were made for the first 30 hatchery-reared and 30 wild conch (tagged individuals) at each outplant site. Burial frequency was quantified as the percentage of conch that had at least part of the shell buried in the sediment, detritus, or algae. Counts for the two sites were pooled for each of the conch types. General observations on locomotory activity were also recorded.

Data from the tag recovery surveys provided information on the movements of free-ranging conch. During each tag recovery the type (wild or hatchery-reared), initial site of transplant (C1 or C2), and number of tagged conch found in different regions around the initial release sites (Fig. 2) were recorded. The total number of conch found in each survey was used to calculate the percentage of hatchery or wild conch from site C1 or C2 in each area surveyed.

Enclosure experiments

Experiment I Enclosure experiments were designed to determine the significance of density-dependent growth and survival of hatchery-reared and wild conch in identical habitats. The first 3-month experiment was conducted from 7 April to 9 July 1990. At each site (C1 and C2) 12 circular pens (30 cm high, 20 m^2) without covers were constructed of vinyl coated wire mesh (2.5 × 5.0 cm). Prior to the experiment (23 February–12 March) three haphazardly placed 25 × 25 cm quadrants per cage were sampled for *Thalassia testudium* components to ensure habitat similarity among the pens, both within and between stations. In each quadrant, seagrass shoot density was estimated, and all above-ground parts were collected into 3–mm mesh nylon bags. Living blades and detritus were separated in the laboratory, dried at 80°C and weighed. Detritus measurements were made again at the end of the experiment (9–13 July 1990) to test for potential depletion of this important food source.

At each site tagged hatchery and wild conch were placed in pens at three different densities, in two random blocks. Stocking densities, spanning the high range of natural densitites in the wild, were 0.5, 1.0, and 2.5 conch·m^{-2} (10, 20, 49 conch·pen^{-1}). The size ranges for hatchery-reared and wild conch were 90–109 mm SL (mean=100, SD=3) and 92–115 mm SL (mean=102, SD=3), respectively. Before stocking the pens with experimental conch, all visible epibenthic predators such as tulip snails, *Fasciolaria tulipa*, apple murex, *Murex pomum*, and the giant hermit crab, *Petrochirus diogenes*, and sea urchins *Tripneustes esculentus* were removed. Every two weeks throughout the experiment, dead conch were replaced to ensure constant density; replacements were not used in growth and survivorship measurements.

Cumulative mortality was calculated by subtracting the number of live conch remaining from the initial loading number. Mortality was examined statistically at the midpoint (day 37) and at the end (day 93) of the experiment. Shell length was measured at the start, near the middle (day 37), and at the end (day 93) of the experiment, and growth rates were calculated for the two periods.

Experiment II A second 3-month enclosure experiment was conducted at sites C1 and C2 to compare survival and growth of hatchery-reared and wild conch in the winter (29 November 1990–21 February 1991). Enclosures built for experiment I were reused in this experiment after having been clear of conch since July 1990. Four enclosures at each site were stocked with 10 hatchery-reared and 10 wild conch (1.0 conch·m^{-2}) gathered from the surrounding free-ranging populations. This density was chosen because highest mean growth rates frequently occurred at this density in enclosure experiment I. The initial size of the hatchery-reared conch ranged from 104–130 mm SL (mean=118, SD=5) and the wild conch ranged from 109–134 mm SL (mean=122, SD=5).

Dead conch were replaced with similar sized free-ranging conch every two weeks. As in the first experiment cumulative mortality and growth rates were determined only for the original stock, not the replacements. Mortality was calculated five times throughout the experiment, and analyzed statistically at the midpoint (day 35) and end (day 84) of the experiment. Growth rates were calculated for two growth periods, 29 November 1990 to 3 January 1991 and 3 January to 21 February 1991.

Tether experiments

Experiment I The first three-month tethering experiment was conducted during the summer (12 April to 11 July 1990) at sites C1 and C2 to examine survivorship, tag effects, and growth rates. The size ranges for hatchery-reared and wild conch were 82–116 mm SL (mean=100, SD=9) and 89–115 mm SL (mean=101, SD=6), respectively. Each conch was secured to a 0.5-m long stainless steel welding rod by a 1 m length of 20-lb test monofilament line that was attached to the shell spire with a clear nylon cable tie. The tether rods were marked with uniquely numbered tags and pushed 40 cm into the substratum approximately 2 m apart. Conch were tethered in four rows of 20 individuals. Each row contained 10 hatchery-reared conch and 10 wild conch in an alternating pattern. For each type of conch, the shell of every second individual was tagged to determine potential tagging effects on conch mortality in the free-ranging experiment.

Cumulative mortality was examined by using the same procedure as enclosure experiment I. Mortality was calculated three times throughout the experiment, and analyzed statistically at the midpoint (day 45) and end (day 90) of the experiment. Growth rates were calculated for two growth periods: 12 April to 27 May and 27 May to 11 July 1990.

Experiment II The second 3-month tethering experiment was conducted during the winter (7 February–3 May 1991) at site C1. Too few of the original hatchery-reared conch remained alive to set up the experiment at the second site. Hatchery-reared conch ranged from 100 to138 mm SL (mean=116, SD=8), and wild conch were 111–133 mm SL (mean=124, SD=5). Tethers were set up as in experiment I with four replicated rows of 20 individuals (10 hatchery-reared and 10 wild conch), except the conch themselves were not tagged. The conch were checked for mortality three times during the experiment and analyzed statistically at days 42 and 84.

Because cable ties were secured behind long apical spines, escape from tether apparatus would be possible only in the event of failure in the cable tie, monofilament line, or connections. Failure appears to be unlikely because nearly all kills observed in this study were found as empty shells attached to the tether apparatus or as crushed shells within 1 m of the original location.

Data Analysis

Analysis of variance (ANOVA), following the guidelines of Day and Quinn (1989), was used extensively in the interpretation of growth and mortality data. The statistical procedures started with full model ANOVA that included all independent effects. When interactions were significant, one- or two-way ANOVAs were performed to examine the effects of site and stock type, the variables most critical in this study. For brevity, non-significant interaction terms in multiple-way ANOVAs are not addressed in the text but are reported in tables. Mortality data were normally examined at the mid-point of individual experiments and at the end.

Cochran's test was used to test for homogeneity of variances. Log and arcsine transformations of data were used in some cases to remove heteroscedasticity; these are noted in the text. Where repeated measurements were made within one experimental enclosure (i.e. growth rates determined for conch in one pen), mean growth rates in the enclosures were used as replicates rather than individual measurements to eliminate pseudoreplication (Hurlburt, 1984). Analysis of covariance (ANCOVA) was used to test for differences in morphological characteristics (shell weight, shell diameter, and tissue weight) between hatchery-reared and wild conch. Shell length was the covariate.

After release, tagged, free-ranging conch dispersed from the initial 1-ha study sites. Chi-square analysis was used to compare dispersion of the two stock types, where the distribution of tagged wild conch was used for the expected frequency in different survey zones.

Results

Conditions at the outplant sites

During the 15–month study period, bottom-water temperature ranged from 24°C in February 1990 to 30°C in late September 1991, then declined rapidly and remained between 24 and 25°C until early May, when temperature rose to 27°C (Fig. 3).

Density estimates made 1 month prior to the beginning of the free-ranging experiment (2 March 1990) showed that the density of conch at site C1 was 16 times higher than at site C2 (Table 1). Between March and May, conch density at site C1 increased to over 1.2 conch·m^{-2}, owing to immigration of the natural population. Transplanted conch from the free-ranging experiment made up 7–15% of the conch in the density estimates; however, on 2 May 1990, transplanted conch accounted for 88% of estimated density. In July, there were nearly equal densities of conch at sites C1 and C2, but in November 1990 and February 1991, densities were close to the original values first observed in March 1990. This may be due to directional changes in movement of conch (towards the northeast) during the winter, which took them away from the transplant sites C1 and C2 (see Behavior).

As expected, shell length measurements taken during the density surveys show an increase in length over time for wild conch tagged at C1 (from mean=105 ± 14 SD in March 1990 to mean=129 ± 13 SD in February 1991)(Table 1). This represents an overall growth rate of 0.07 mm·day^{-1}, similar to that measured in free-ranging tagged conch. No growth rate was calculated for C2, because density surveys yielded low numbers; however, the mean sizes appear to be comparable to those measured at site C1 (Table 1).

Handling and tag effects

Transporting hatchery-reared conch appeared to have little adverse effect on their subsequent survivorship in the field. Conch were left out of water for 7 hours, and all remained alive during the 7 days after transport while they were tagged and placed in enclosures for Experiment I.

Table 2

Mortality of tagged and untagged queen conch (*Strombus gigas*) on tethers at the two experimental sites. Ten tagged and ten untagged conch were tethered in each of four replicate blocks at each site. Values are mean percent mortality ± SD (number of dead conch).

	Mortality	
Site	Tagged	Untagged
C1	52.5 ± 12.6 (21)	45.0 ± 12.9 (18)
C2	40.0 ± 21.6 (16)	52.5 ± 9.6 (21)

In the first tethering experiment percent mortalities (arcsine-transformed) did not differ among any of the tag and site treatments (Table 2) (ANOVA, $F_{3,12}$=0.722, P =0.558 for C1; $F_{3,12}$=0.679, P =0.581 for C2).

Free-ranging experiment

Tag recovery Tag recapture rates for free-ranging juvenile conch were related to both stock type and location (Table 3, Fig. 4). Exhaustive searches in and beyond the study area recovered all visible live conch, and there is no reason to believe that hatchery conch were seen and collected by the divers less often than wild conch. In fact, wild conch had burial rates higher than hatchery conch (see Behavior); therefore, the reverse bias is more likely.

In November 1990, approximately 7.5 months after initial release, 206 of hatchery-reared conch were recovered from site C1 and 248 from C2, an overall recapture of 9% of the original release (Fig. 4). Recoveries of wild conch from sites C1 and C2 numbered 542 and 820 conch, respectively, an overall recapture rate of 28%. The highest proportion of loss occurred during the first two months (April and May 1990). After May, recovery curves for both hatchery and wild conch leveled off at both sites. Tag recapture was consistently higher for wild conch released at site C2 (34% at experiment end) than for those released at C1 (22%), despite the presence of large num-

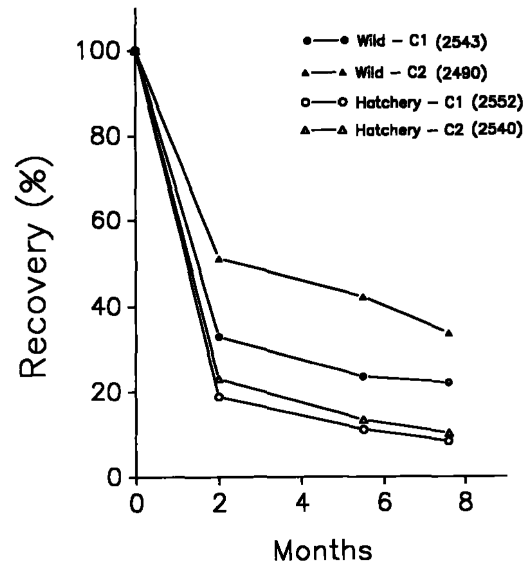

Figure 4

Recovery rates for free-ranging hatchery-reared and wild queen conch, *Strombus gigas*, transplanted to sites C1 and C2 in April 1990. Values are percentages of the original conch (April releases) found in June, September, and November surveys. In parentheses are the original numbers of tagged conch.

Table 3

Tag recovery summaries for hatchery-reared and wild queen conch (*Strombus gigas*) released in two study sites near Children's Bay Cay, Bahamas, in 1990. Adjustments to the original numbers of conch released in April account for tagged conch taken from the free-ranging study to be used in enclosure and tether experiments; these were subtracted from the original number.

	Site			
	C1		C2	
Stock type	Hatchery	Wild	Hatchery	Wild
April to June (64 days)				
Original Number Released in April	2552	2543	2540	2490
Recovered Live	480	837	586	1270
% Recovered Live	18.8	32.9	23.1	51.0
June to September (100 days)				
Adjusted Number Released	2517	2467	2472	2451
Recovered Live	277	582	328	1035
% Recovered Live	11.0	23.6	13.3	42.2
September to November (66 days)				
Adjusted Number Released	2502	2452	2457	2436
Recovered Live	206	542	248	820
% Recovered Live	8.2	22.1	10.1	33.7

bers of untagged, wild conch at the C1 area. Hatchery stocks were recovered in about equal proportions at the two sites.

Growth Free-ranging wild conch had higher growth rates (log-transformed) than hatchery-reared conch during all three seasons examined (Table 4). During summer, the difference was approximately two times (Fig. 5), but the rates began to converge in the fall. Growth rates were highest during summer and fall, and lowest during winter, following patterns of water temperature (Fig. 3). Conch grew significantly faster at site C2 than at C1 during both summer and winter; site differences were not significant in the fall (Table 4, Fig. 5).

Morphology At the beginning of the free-ranging experiment, shells of hatchery-reared conch were significantly lighter than those of wild conch from the Children's Bay Cay nursery site (slopes were homogeneous, F=0.833, P=0.365; ANCOVA: F=92.62, P< 0.001) (Fig. 6A). Lower shell weight in hatchery-reared conch is a function of either thinner shells or differences in shell form compared to wild conch. Regressions of shell width with shell length (Fig. 6B) showed that the spines were, in fact, longer in wild conch than in hatchery-reared stock (slopes were homogeneous, F=1.76, P= 0.190; ANCOVA: F=73.99, P< 0.001). Regressions of tissue wet weight with shell length show no significant difference in tissue weight between wild and hatchery-reared conch (Fig. 6C), (slopes were homogeneous, F=1.76, P=0.190; ANCOVA: F=3.24, P=0.077).

Measurements made on shells of hatchery-reared and wild conch at the end of the experiment in February 1991 show that lines for shell weight and width had converged (Fig. 7, A and B). Shell weights of hatchery-reared conch were still lighter than those of wild conch (slopes were homogeneous, F=0.189, P=0.665; ANCOVA: F=7.44, P=0.008) (Fig. 7A), but the lines were closer than in April 1990 (Fig. 6A). Stock type did not affect the relationship between shell length and shell width in February (Fig. 7B) (slopes were homogeneous, F=2.01, P=0.160; ANCOVA: F=0.957, P=0.331). Hatchery-reared conch

Table 4

Results of two-way ANOVAs for growth rates in free-ranging queen conch (*Strombus gigas*). "Site" refers to the two experimental sites C1 and C2. "Stock type" refers to hatchery-reared versus wild conch.

Source	df	MS	F	P
Period I (April to September 1990—64 days)				
Site × stock type	1	<0.001	1.205	0.273
Site	1	0.003	22.157	0.001
Stock type	1	0.045	322.407	<0.001
Error	396	<0.001		
Period II (September to November 1990—100 days)				
Site × stock type	1	<0.001	1.332	0.249
Site	1	<0.001	0.418	0.518
Stock type	1	0.004	16.967	<0.001
Error	396	<0.001		
Period III (November 1990 to February 1991—66 days)				
Site × stock type	1	<0.001	0.714	0.400
Site	1	0.001	7.541	0.007
Stock type	1	0.001	8.697	0.004
Error	115	<0.001		

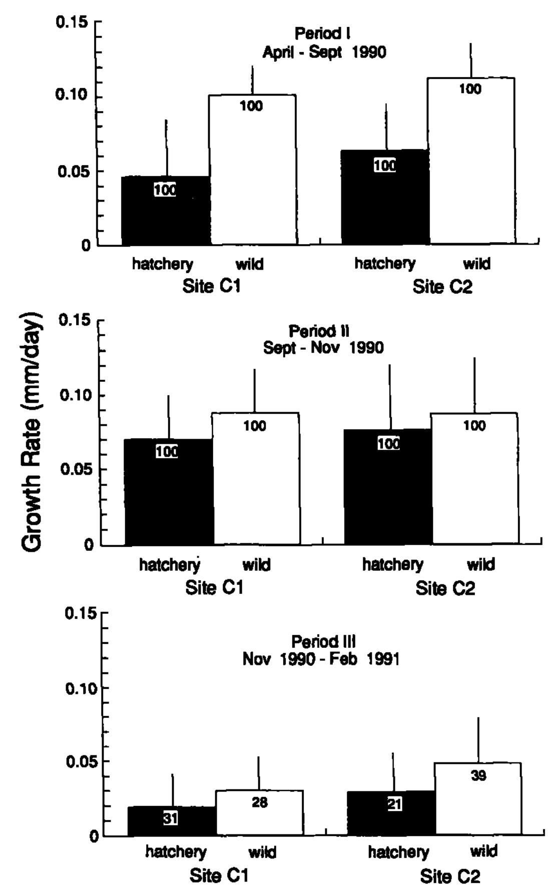

Figure 5

Comparison of growth rates of free-ranging hatchery-reared and wild queen conch, *Strombus gigas*, at sites C1 and C2. Growth periods I–III represent summer, fall, and winter, respectively. Values are mean ± SD, with the number of conch measured shown inside the vertical bars.

had heavier tissue wet weight than wild conch (slopes were homogeneous, F=0.163, P=0.688; ANCOVA: F=7.12, P= 0.010) (Fig. 7C). This can be explained by examining the ratio between tissue and shell weight. At the beginning of the experiment these ratios for hatchery and wild conch were 0.34 ± 0.04 and 0.22 ± 0.03 (mean ± SD), respectively. This indicates that hatchery conch had lighter shells and heavier soft tissue than wild conch. At the end of the experiment ratios for hatchery and wild conch were 0.30 ± 0.04 and 0.25 ± 0.04 (mean ± SD), respectively. The lower ratio for hatchery conch indicates that both the tissue and shell weight were increasing.

Hatchery-reared conch that survived 11 months in the field either developed morphological characteristics of wild conch, or the survivors had such characteristics at release. Because there was little overlap in regressions of shell width versus shell length at the beginning of the experiment, change in shape is the most plausible explanation for characteristics measured in hatchery-reared conch at the end of the experiment. Presence of short spines on pretran-

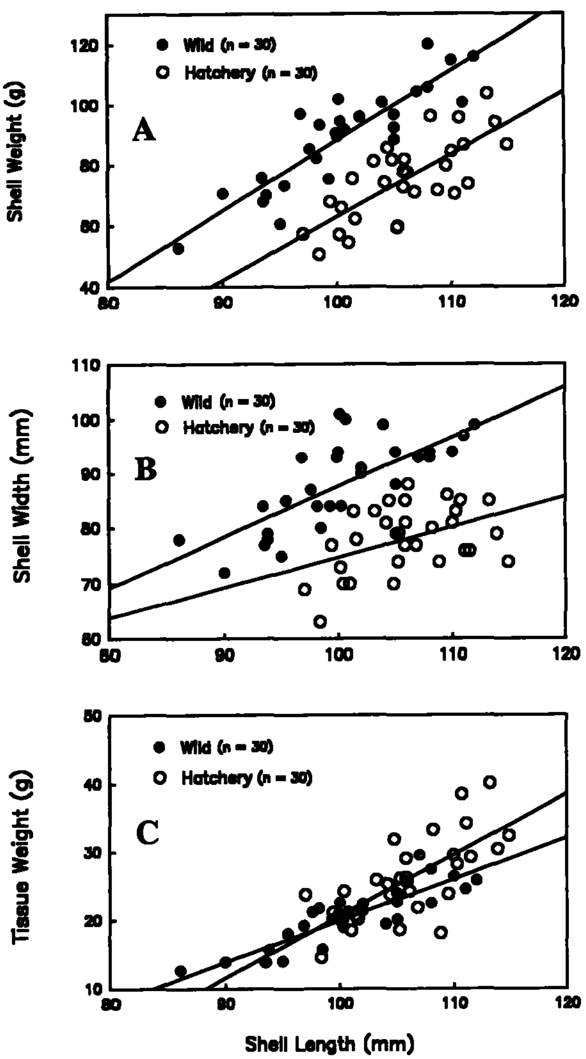

Figure 6

Shell weights (**A**), shell widths (**B**), and tissue weights (**C**) of hatchery-reared and wild queen conch, *Strombus gigas*, shown as a function of shell length. Measurements were taken for conch of each stock type collected at the beginning of the free-ranging experiment (1 April 1990).

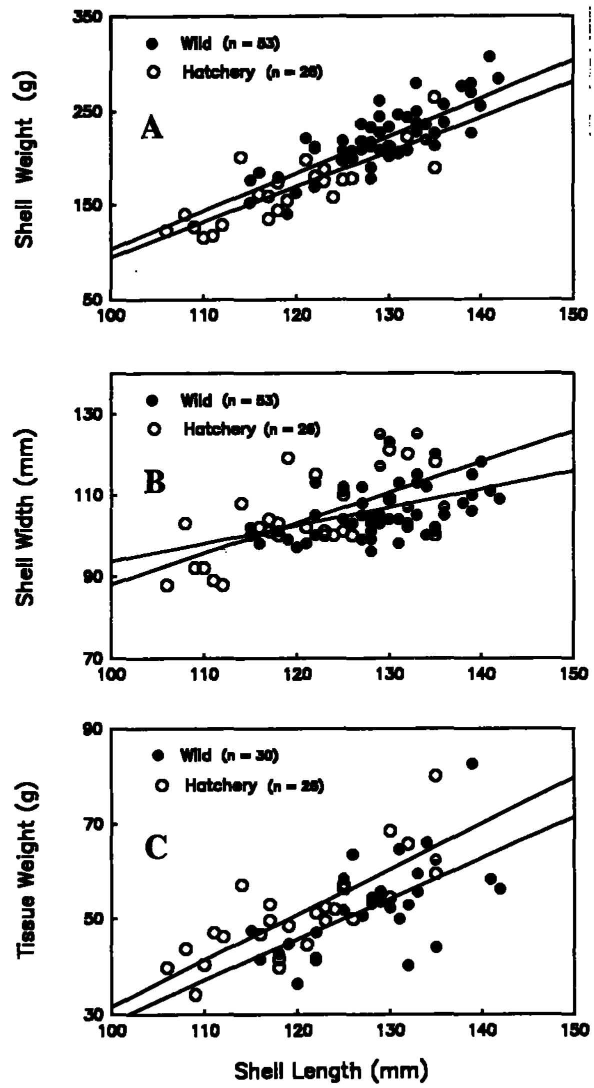

Figure 7

Shell weights (**A**), shell widths (**B**), and tissue weights (**C**) of hatchery-reared and wild queen conch, *Strombus gigas*, shown as a function of shell length. Measurements were taken for conch of each stock type collected at the termination of the free-ranging experiment (21 Feb. 1991).

splant portions of the shells followed by long spines on the outer (newer) portions of the last shell whorl support the hypothesis of changing shell shape. Although it is normal for spine length to increase proportionally with shell length in queen conch, the posttransplant increase in hatchery-reared stock was extreme and obviously disproportionate in most shells.

Behavior On all nine dates when burial was examined for free-ranging animals, a higher percentage of wild conch were buried than of hatchery-reared individuals (Fig. 8). Pairwise ANOVA of burial frequency on arcsine-transformed data from dates as blocks showed that the difference in burial rates between stock types was significant ($F_{1,15}$=8.51, P=0.011). Hatchery and wild conch showed nearly parallel patterns of burial frequency over time. However, plots of burial frequency should not be interpreted as seasonal trends, because juvenile conch appear to demonstrate tidal periodicity in locomotory activity (pers. observ.). Although the patterns were not quantified, it was frequently noted during field observations that hatchery conch were more active than wild conch. While hatchery-reared individuals were almost always moving, wild conch were frequently found nestled motionless beneath algae or detritus.

Given the relatively small area of the two outplant sites (1 ha each) tagged conch often dispersed relatively far from their original release sites (Fig. 9, A and B). For example, in June 1990 only 15% of the recovered hatchery-reared conch released at site C1 were found in that zone and 35% were found northwest of C1. Tagged conch tended to move to the northeast and northwest between April and June 1990. By June, hatchery-reared and wild conch initially released at site C1 were widely dispersed and differentially distributed (χ^2=18.01, df=4, P=0.05). Hatchery-reared conch released at C2 tended to disperse more widely than wild conch (i.e., from the southwest sandbar to the north zones); the difference was significant (χ^2=255.6, df=6, P=0.05). Wild conch moved toward the center zone between site C1 and C2 (Fig. 9B). Between June and September 1990 a large percentage of conch released at site C1 were found between C1 and C2 (Fig. 9A), while conch from site C2 continued to be found north of the release area (Fig. 9B). In both cases the difference in dispersion between hatchery and wild was significantly different (C1: χ^2=-6.4, df=5, P=0.05; C2: χ^2=17.6, df=5, P=0.05). By November 1990, hatchery and wild conch released at site C1 (χ^2=9.1, df=5, P=0.05) and C2 (χ^2=12.6, df=6, P=0.05) had similar distributions. Conch released at site C2 consistently moved toward the adjacent natural juvenile population centered at C1 (see Fig. 2).

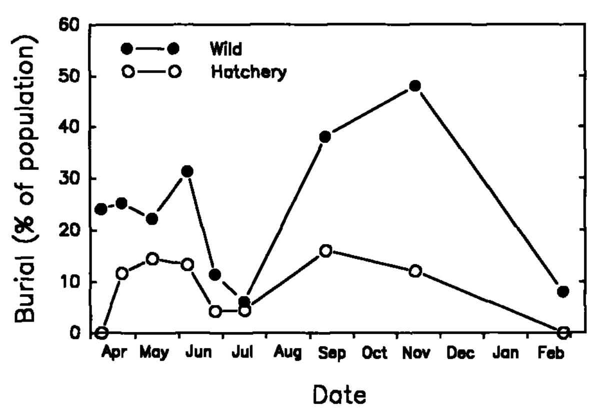

Figure 8
Percentage of queen conch, *Strombus gigas*, buried during each observation for hatchery-reared and wild conch. Values are based upon observations on 30 haphazardly chosen conch of each stock type on each date.

Enclosure experiments

Experiment I

Mortality In the first enclosure experiment (7 April to 9 July 1990), mortality data for the midpoint and end of the experiment (Fig. 10) were examined with two separate three-way ANOVAs, by using numbers of dead conch (Table 5). Except when highest mortality occured at site C2 at the end of the experiment, mortality did not differ between sites or among the three stocking densities. Differences in mortality between stock types were never significant in the enclosures (Table 5).

Growth Trends of growth (log-transformed) in the first enclosure experiment (Fig. 11) were similar to those observed in free-ranging conch during the summer (Fig. 5) (i.e. rates were higher at C2 than at C1, and wild conch grew faster than hatchery conch). In growth period I (7 April–14 May 1990), wild and hatchery conch grew faster at site C2 than at C1, and wild conch grew faster than hatchery conch at both sites (Table 6). There was also a significant density effect (Table 6); highest growth occurred in conch held at 1.0 individuals·m^{-1} (Fig. 11).

In growth period II (14 May–9 July 1990), there were numerous two-way interactions in the ANOVA (Table 6), particularly at site C1. In one-way ANOVAs, there was no density effect for hatchery ($F_{2,3}$ = 5.74, P=0.094) or for wild ($F_{2,3}$ =7.139, P=0.072) conch at site C1; however, hatchery and wild conch

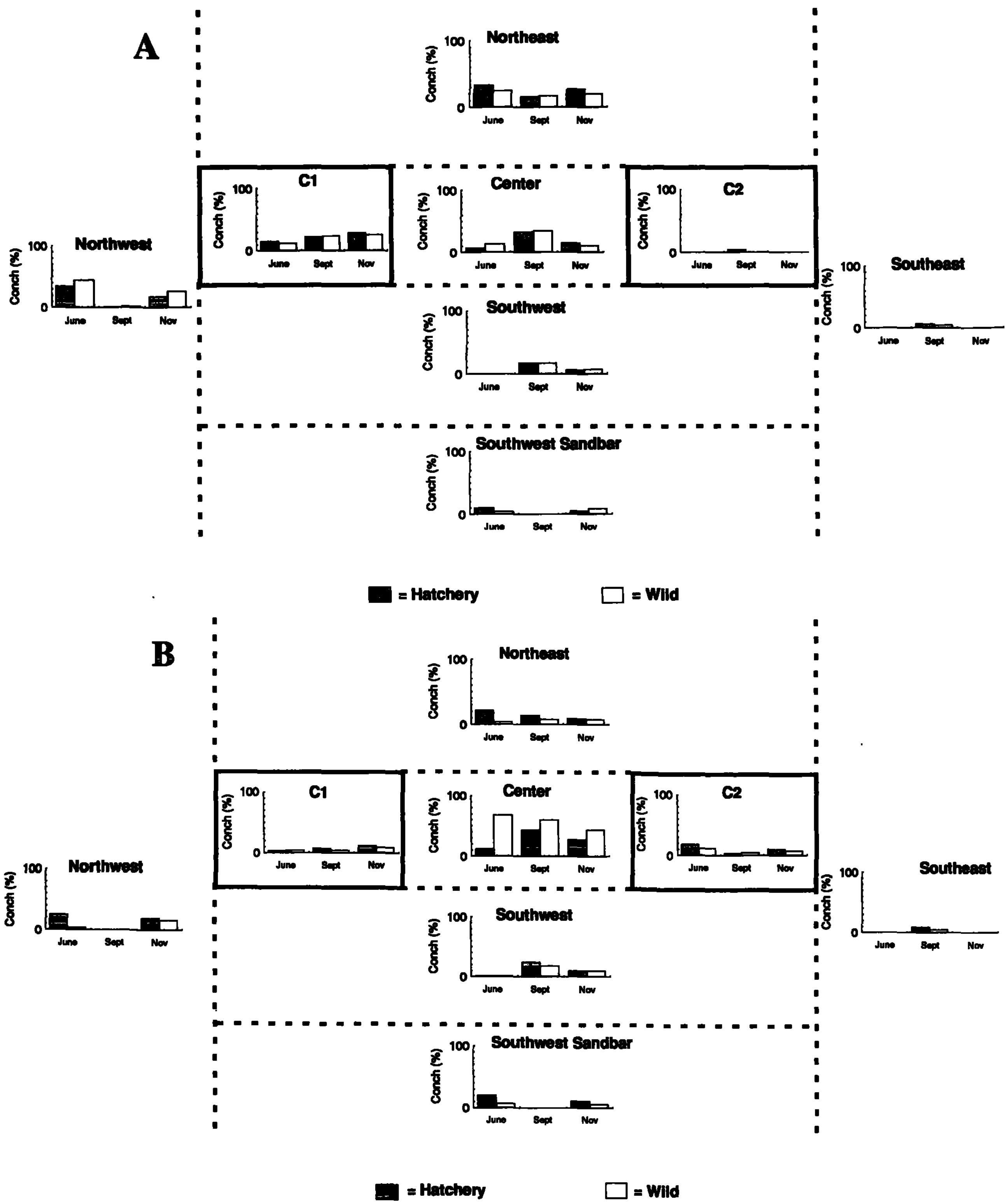

Figure 9

Recoveries of tagged queen conch, *Strombus gigas*, in the eight zones (not to scale) searched during the June, September, and November surveys. Values shown are the percentages of total capture for each stock type found in each zone, (**A**) conch released at site C1, and (**B**) conch released at site C2. See Figure 2 for true distances between the zones.

Table 5

Results of three-way ANOVAs for mortality of queen conch (*Strombus gigas*) in enclosure experiment I. "Site" refers to the two experimental sites C1 and C2. "Stock type" refers to hatchery-reared versus wild conch. "Density" is the density of conch tested in enclosures.

Source	df	MS	*F*	*P*
Period I (7 April to 14 May 1990—37 days)				
Site × type × density	2	0.015	1.266	0.317
Site × stock type	1	0.015	1.259	0.284
Site × density	2	0.003	0.258	0.777
Stock type × density	2	0.003	0.281	0.760
Site	1	0.028	2.400	0.147
Stock type	1	0.004	0.353	0.564
Density	2	0.001	0.108	0.898
Error	12	0.012		
Period II (14 May to 9 July 1990—56 days)				
Site × type × density	2	0.018	1.465	0.270
Site × stock type	1	0.010	0.839	0.378
Site × density	2	0.001	0.109	0.897
Stock type × density	2	0.018	1.447	0.273
Site	1	0.095	7.710	0.017
Stock type	1	0.008	0.691	0.422
Density	2	<0.001	0.028	0.973
Error	12	0.012		

differed in growth rate ($F_{1,10}$=10.75, P=0.008). At site C2 there were no differences in growth rate either between hatchery and wild conch or among the stocking densities (Table 6).

Prior to the beginning of the enclosure experiment, pen locations were chosen for similarity in macrophyte characteristics (Table 7). Seagrass shoot density ($F_{23,48}$=0.55, P=0.938) and macrophyte biomass ($F_{23,48}$=1.37, P=0.177) did not differ among the 24 cages. Although ANOVA showed that detritus differed ($F_{23,48}$=2.00, P=0.022) among the cages, Tukey's multiple comparison test did not detect the differences (P>0.05). At the end of the experiment dry weight of seagrass detritus did not differ among the cages (Table 7)($F_{23,24}$=0.900, P=0.598), and there were no differences in individual cages between the beginning and end of the experiment ($F_{1,142}$=0.090, P=0.764). There is no evidence, therefore, that detritus was depleted even at the high density of 2.5 conch·m^{-2}. When comparing shoot density between the beginning and end of the experiment, there was no difference ($F_{1,142}$=2.95, P=0.088), but biomass of living seagrass did differ between the dates ($F_{1,142}$=37.01, P<0.001), probably related to blade growth in the spring season.

Experiment II

Mortality At the termination (day 85) of enclosure experiment II (29 November 1990–21 February 1991) mortality was obviously higher at site C2 than at C1 for both hatchery and wild conch (Fig. 12), similar to the results of enclosure experiment I (Fig. 10). Midway through the experiment there was no significant mortality difference between site C1 and C2; however, the difference was significant by the end of the experiment (Table 8); mortality was higher at site C2. Similar to enclosure experiment I, there were no differences in mortality between hatchery and wild conch (Table 8).

Growth Growth rates were low in enclosure experiment II (0.01–0.06 mm·d^{-1}) (Fig. 13), paralleling the trend observed in free-ranging conch (Fig. 4) and associated with low winter temperatures (Fig. 3). There were significant site × stock type interactions for period I ($F_{1,12}$=5.949, P=0.031) and period II ($F_{1,12}$=5.004, P=0.045) because of differences in growth rate between hatchery and wild conch at site C1 (period I: $F_{1,6}$=6.48, P=0.044; period II: $F_{1,6}$=9.747, P=0.021); but not at site C2 (period I: $F_{1,6}$=0.008, P=0.932; period II: $F_{1,6}$=0.207, P=0.665). At site C1 wild conch grew approximately twice as fast as hatchery conch.

Tether experiments

Experiment I

Mortality The first tether experiment, conducted from 11 April to 11 July 1990, confirmed that the difference in tag recovery rate between hatchery-reared and wild conch was related to predation (Fig. 14). Hatchery conch were killed at a frequency approximately twice that of wild conch for day 45 and day 88 (Table 9, Fig. 14). Site effects were not significant at either midpoint or end of the experiment (Table 9, Fig. 14).

Growth Growth rates in both hatchery and wild conch on tethers were higher at site C2 than at site C1 by the end of the study period (11 July 1990) (Fig. 15). This difference also occurred in free-ranging conch (Fig. 5) and enclosure experiment I (Fig. 11). During period I (April and May 1990) there was a significant site × type interaction (Table 10) because wild conch grew faster at site C2 than C1 ($F_{1,64}$=49.28, P<0.001), and hatchery conch grew at

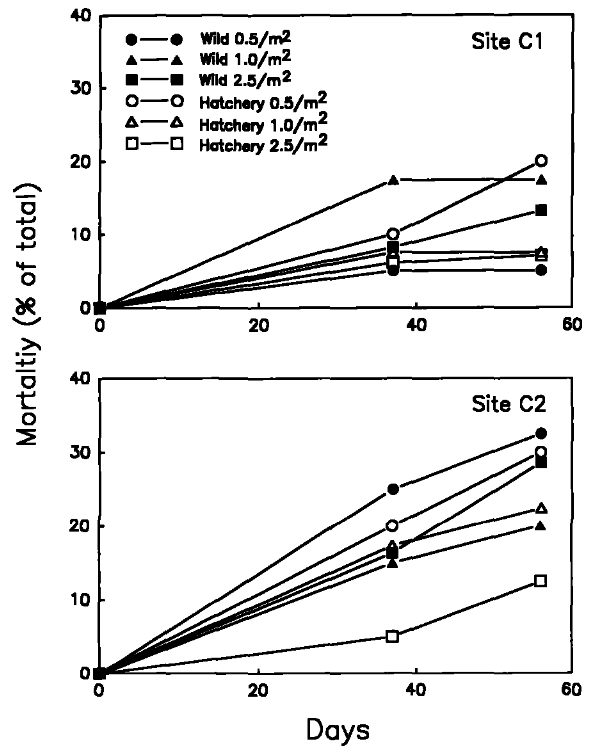

Figure 10

Cumulative mortality curves for enclosure experiment I. Hatchery-reared and wild queen conch, *Strombus gigas*, were held at three different densities at sites C1 and C2. Initial numbers of conch in the enclosures were 10, 20 and 49, yielding densities of 0.5, 1.0, and 2.5 conch·m^{-2}, respectively.

Table 6

Results of multi-way ANOVAs for growth rates of queen conch (*Strombus gigas*) in enclosure experiment I. Sources are the same as described in Table 5.

Source	df	MS	*F*	*P*
3-way ANOVA for Period I				
(7 April to 14 May 1990—37 days)				
Site × type × density	2	<0.001	0.481	0.630
Site × stock type	1	<0.001	0.893	0.363
Site × density	2	<0.001	2.456	0.128
Stock type × density	2	<0.001	2.284	0.144
Site	1	0.001	28.210	<0.001
Stock type	1	<0.001	16.511	0.002
Density	2	<0.001	4.649	0.032
Error	12	<0.001		
3-way ANOVA for Period II				
(14 May to 9 July 1990—56 days)				
Site × type × density	2	<0.001	3.546	0.062
Site × stock type	1	0.001	8.722	0.012
Site × density	2	<0.001	1.281	0.313
Stock type × density	2	<0.001	4.261	0.040
Site	1	<0.001	0.778	0.395
Stock type	1	0.0022	3.171	<0.001
Density	2	<0.001	4.787	0.030
Error	12	<0.001		
2-way ANOVA for Period II (Site C1)				
Stock type × density	2	0.001	9.513	0.014
Stock type	1	0.002	36.836	0.001
Density	2	<0.001	4.619	0.061
Error	6	<0.001		
2-way ANOVA for Period II (Site C2)				
Stock type × density	2	<0.001	0.015	0.985
Stock type	1	<0.001	1.465	0.272
Density	2	<0.001	1.935	0.225
Error	6	<0.001		

the same rate at both sites ($F_{1,43}$=0.105, P= 0.747). Wild conch grew significantly faster than hatchery conch at site C1 ($F_{1,55}$=14.54, P<0.001) and C2 ($F_{1,52}$=69.06, P<0.001) (Fig. 15). In growth period II (June and July 1990) wild conch grew faster than hatchery conch at both sites (Table 10, Fig. 15).

Experiment II A second tether experiment conducted at site C1 from 7 February to 3 May 1991, using wild conch and the few remaining hatchery-reared conch from the free-ranging experiment, resulted in mortality curves (Fig. 16) different from the first tether experiment (Fig. 14). Mortality rates did not differ between stock types at either 42 ($F_{1,6}$=0.871, P=0.387) or 84 days ($F_{1,6}$<0.001, P=1.000). Mortalities were identical (65%) at the 84-day termination of the experiment (Fig. 16).

Comparison of experiments

Mortality rates in hatchery-reared conch were higher than or equal to those of wild conch in all experiments and at both study sites (Table 11). Equivalent mortality rates were found in enclosures and in tether experiment II run at the end of the study period. Growth rates were higher in wild conch than in hatchery-reared conch except during the second 5-week period of enclosure experiment I at site C2 and in enclosure experiment II at site C2, when growth rates were equivalent.

Site differences in mortality rates were relatively consistent across experiments and stock types (Table 11). Mortality was always lower for both wild and hatchery-reared conch at site C1 than at C2, except for equivalent mortality rates measured in tether experiment I. Most experiments showed that growth rates were lower at site C1 than at C2 with certain exceptions (Table 11). A significantly higher growth rate was found at C1 in wild conch during the second enclosure experiment, and equivalent growth rates were found in hatchery-reared conch in the same experiment. Growth rate did not differ between sites during fall in free-ranging conch.

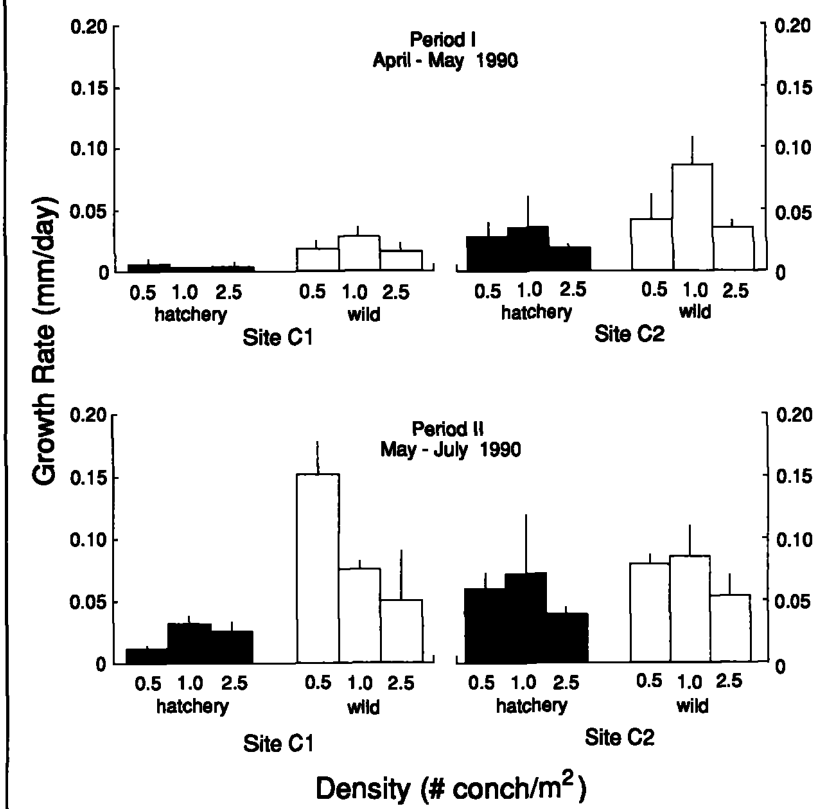

Figure 11

Growth rate comparisons for enclosure experiment I. Hatchery-reared and wild queen conch, *Strombus gigas*, were held at three different densities at sites C1 and C2. Values are mean ± SD for average growth rates in two replicate enclosures.

Discussion

Importance of seed stock quality

Stock enhancement and rehabilitation depend upon the ability of fisheries managers to place viable seed animals in optimal habitats at appropriate times (Stoner, in press). Hatcheries in the Turks and Caicos Islands, Belize, Mexico, and Florida are now producing juvenile queen conch with the expectation that hatchery-reared conch will be seeded into local waters for restoration of depleted resources. Releases of hatchery-reared conch in several small-scale pilot programs have been relatively unsuccessful in terms of conch survival (Appeldoorn and Ballantine, 1983; Appeldoorn, 1984; Iversen et al., 1986; Coulston et al., 1987; Rathier, 1987; Davis et al., 1992), but it is unknown whether low survivorship was related to characteristics of the habitat or the outplanted conch. The only published field comparison of wild and hatchery-reared queen conch (Marshall et al.[2]) showed that hatchery-reared conch may be more vulnerable to predation than are wild conch. Additionally, Jory and Iversen (1988) found that hatchery-reared conch may have shells with lower breaking strengths than those of wild conch. The present study shows that potential differences in physiology, behavior, morphology, and survival must all be considered.

Differences in growth rate between wild and hatchery-reared conch at Children's Bay Cay study sites are surprising given that the hatchery conch had been in a field grow-out enclosure with natural substrata and food for 6 months. Several explanations

Table 7

Seagrass components in 24 cages at the beginning and end of enclosure experiment I. *Thalassia* biomass included all above-ground live blades. *Thalassia* detritus included senescent and decomposing seagrass blades retained in a 3 mm mesh bag. Values are mean (± SD).

Seagrass components	March 1990	July 1990
Thalassia shoot density (shoots·m^{-2})	674.1 (±92.2)	649.3 (±79.8)
Thalassia biomass (g dry wt·m^{-2})	77.2 (±18.5)	107.2 (±37.5)
Thalassia detritus (g dry wt·m^{-2})	317.9 (±131.7)	324.32 (±25.4)

[2] Marshall, L. S., Jr., C. Cox, and R. N. Lipcius. 1992. Survival of wild and hatchery-reared juvenile queen conch in natural habitats. Unpubl. manuscr.

Table 8

Results from two-way ANOVAs for mortality of queen conch (*Strombus gigas*) in enclosure experiment II. Sources are the same as described in Table 4.

Source	df	MS	*F*	*P*
Period I (29 November 1990 to 3 January 1991—35 days)				
Site × stock type	1	0.563	0.239	0.634
Site	1	5.063	2.150	0.168
Stock type	1	0.563	0.239	0.634
Error	12	2.354		
Period II (3 January to 21 February 1991—50 days)				
Site × stock type	1	0.250	0.143	0.712
Site	1	110.250	63.000	<0.001
Stock type	1	0.250	0.143	0.712
Error	12	1.750		

Table 9

Results of two-way ANOVAs for mortality of queen conch (*Strombus gigas*) in tether experiment I. Sources are the same as described in Table 4.

Source	df	MS	*F*	*P*
Period I (12 April to 27 May 1990—45 days)				
Site × stock type	1	1.563	0.926	0.355
Site	1	0.063	0.037	0.851
Stock type	1	14.063	8.333	0.014
Error	12	1.688		
Period II (27 May to 11 July 1990—45 days)				
Site × stock type	1	<0.001	<0.001	1.000
Site	1	0.250	0.098	0.759
Stock type	1	12.250	4.820	0.049
Error	12	2.542		

Table 10

Results of two-way ANOVAs for growth rates of queen conch (*Strombus gigas*) in tether experiment I. Sources are the same as described in Table 4.

Source	df	MS	*F*	*P*
Period I (12 April to 27 May 1990—45 days)				
Site × stock type	1	0.004	28.152	<0.001
Site	1	0.005	31.072	<0.001
Stock type	1	0.014	85.104	<0.001
Error	107	<0.001		
Period II (27 May to 11 July 1990—45 days)				
Site × stock type	1	<0.001	0.535	0.467
Site	1	0.016	50.410	<0.001
Stock type	1	0.002	7.629	0.007
Error	72	<0.001		

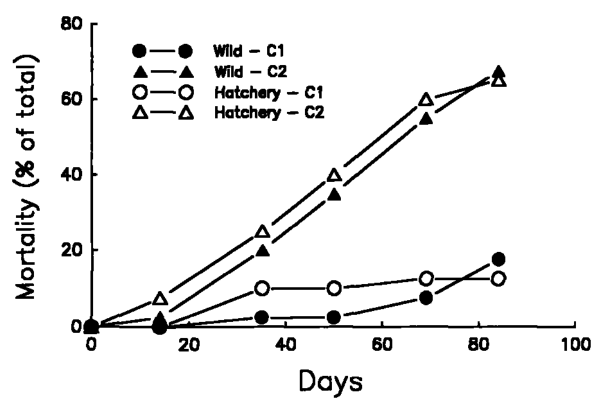

Figure 12

Cumulative mortality curves for enclosure experiment II. Hatchery-reared and wild queen conch, *Strombus gigas*, were compared at sites C1 and C2. Forty conch of each stock type were held at each site.

may be speculated: 1) hatchery and wild conch were different in their metabolic functions, such as partitioning of energy into somatic and shell growth, 2) slow growth in hatchery-reared conch was a sublethal effect of transport, or 3) poor growth was related to behavioral characteristics of hatchery-reared conch, such as a reduced ability to recognize foods in the new habitat or unusually high motility. Laboratory experiments by Siddall (1984b) showed that 10-mm juvenile queen conch held at high density had high locomotory activity and associated low growth rates. Seemingly constant motion and lack of burial in our hatchery-reared animals suggest that their metabolic demands may have been high. However, high growth rates in the hatchery conch later in our investigation showed that the problem was not a permanent characteristic of the stock type, and others have shown that hatchery-reared conch can have normal growth rates in the field (Appeldoorn and Ballantine, 1983; Davis et al., 1992). Nevertheless, as suggested earlier (Stoner and Sandt, 1991, 1992), growth appears to be a very sensitive indicator of a seed animal's physiological performance in a new habitat.

A more serious difference occurred in mortality rates. From the first field experiments with hatchery-reared queen conch juveniles (Appeldoorn and Ballantine, 1983) it has been clear that small conch are highly susceptible to predation. Recommendations for release size range from 4 cm shell length

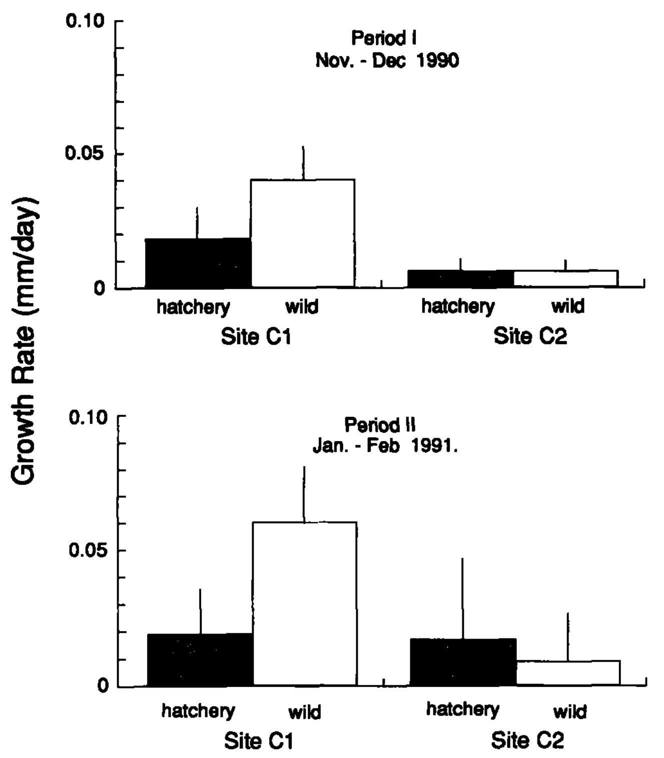

Figure 13

Growth rate comparisons for enclosure experiment II. Hatchery-reared and wild queen conch, *Strombus gigas*, were held at 1.0 conch·m^{-2} at sites C1 and C2. Values are mean ± SD for average growth rates in four replicate enclosures.

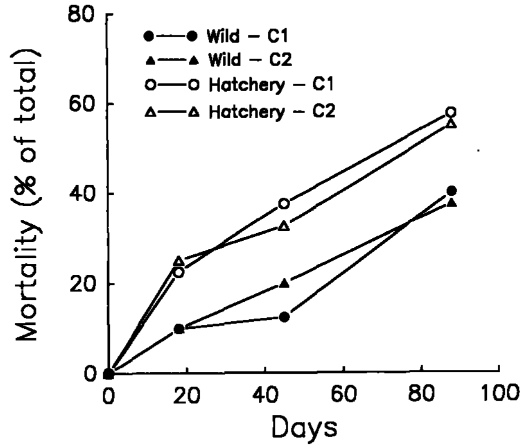

Figure 14

Cumulative mortality curves for tether experiment I. Hatchery-reared and wild queen conch, *Strombus gigas*, were compared at sites C1 and C2. Forty conch of each stock type were tethered at each site.

(Berg, 1976) to 10 cm or larger (Jory and Iversen, 1983). Even with the use of 8–12 cm shell length test animals in this investigation, hatchery-reared conch on tethers were killed at a rate nearly twice the rate of wild conch early in the study. Morphological and behavioral differences are probably the most important factors influencing mortality. Thin shells and short apical spines observed in the hatchery-reared conch would present a smaller, more vulnerable prey to predators. Palmer's (1979) experiments have shown that spination is an important shell characteristic for minimizing predation in intertidal gastropods.

Shell weight and spination are malleable traits in queen conch. Alcolado (1976) observed that shell form in the species was related to water depth and habitat type, with thin shells and short-spines being associated with rapid growth in shallow water. Environmental mediation of shell form was tested experimentally by Martin-Mora (1992) near Lee Stocking Island. She found that transplanted wild conch took on the morphology of local conch within several months, and that high shell weight and long spines were associated with slow growth rate. Given the importance of shell quality in molluscan biology, attention has been given to relationships between shell properties and diets, substrata, temperature, salinity, and other physical factors (Wilbur, 1964; Carter, 1980). It is likely, therefore, that culture techniques can be developed to provide seed conch which are less vulnerable to predation.

Survivorship of hatchery-reared conch may also have been influenced by their low burial frequency. Wild conch tend to shelter under detritus or algae, and remain partially buried and unmoving for long periods of time. This probably provides a certain degree of protection from larger visual predators. Low burial frequency in hatchery-reared conch may be related to the fact that the field grow-out area in the Caicos Islands, where they spent several months before being transplanted to the Exuma Cays, was primarily a hard-bottom environment. Behavioral differences between hatchery-reared and wild stocks are rarely documented; however, Schiel and Welden (1987) found that hatchery-reared red abalone, *Haliotis rufescens*, did not move to concealed locations as did wild abalone, resulting in higher predatory mortality.

There are at least three limitations of the present investigation. One is not knowing whether convergence in the morphology and survivorship of wild and hatchery-reared conch was related to

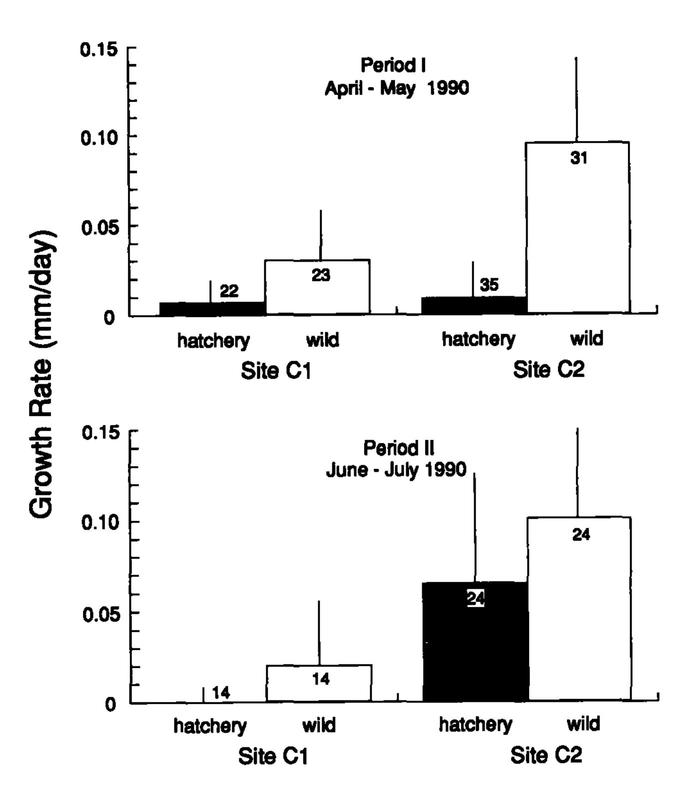

Figure 15
Growth rates of hatchery-reared and wild queen conch, *Strombus gigas*, held on tethers at sites C1 and C2 during experiment I. Values are mean ± SD, with the number of conch measured shown inside the vertical bars.

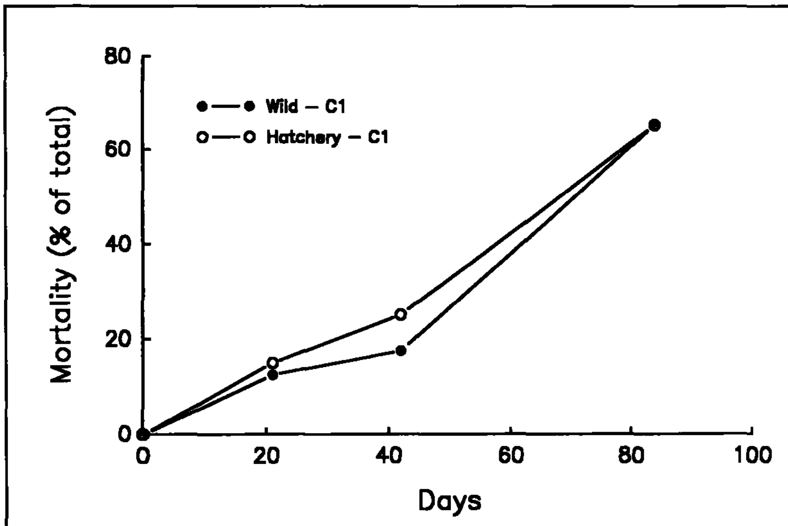

Figure 16
Cumulative mortality curves for hatchery-reared and wild queen conch, *Strombus gigas*, held on tethers at site C1 during experiment II. Forty conch of each stock type were tethered at each site.

adaptation by individuals over the course of the investigation, or is explained simply by differential survivorship (i.e. the most fit hatchery-reared conch survived to the end of the experiments). As discussed earlier, a strong case for adaptation can be made because of the obvious changes in shell morphology over time within individual conch. Second, hatchery-reared conch used in this study were from one season's production in a single hatchery. We know that different hatcheries and different cultures from individual hatcheries can produce conch with different characteristics. For example, Jory and Iversen (1988) found different shell strengths among cultures of queen conch. Because juvenile conch are reared from egg masses collected from the wild, and because both shell morphology and behavior appear to be relatively plastic characteristics in queen conch, we believe that differences shown between hatchery-reared animals and native stocks can be alleviated through modifications in diets, hatchery substrata, and other culture techniques. Field viability must be considered continuously throughout the hatchery-rearing process. Third, morphological effects on survival may vary with site because of differences in predator assemblages. For example, at a site where molluscs (such as tulip snails, *Fasciolaria tulipa*) are the most important predators, size and escape behavior may be more important than spine length and shell thickness. More site comparisons and better knowledge of predator-prey relationships are needed.

Importance of stock enhancement sites

Site selection for stock enhancement with queen conch is a complex issue and the subject of several earlier papers (Stoner and Sandt, 1991, 1992; Stoner et al., 1993; Stoner, in press). It is clear from experiments reported here that even carefully chosen locations, such as our non-conch study site C2, may not support juvenile conch over the long term. Conch at this site demonstrated consistently higher growth than conch at the traditional nursery site (C1), but mortality was also higher in both tethered and free-ranging conch.

Site differences in mortality could be associated with patterns of predator abundance or diversity, or both. Although predators may accumulate where prey density is high, the most likely explanation for lower predation rate at site C1

Table 11

Summary of results from free-ranging, enclosure, and tether experiments on mortality and growth of hatchery-reared and wild queen conch (*Strombus gigas*) at two field sites (C1 & C2). W = wild conch. H = hatchery-reared conch. PI, PII, and PIII refer to different growth periods within the experiment. Signs indicate statistically significant differences (see text).

	Stock type		Differences	
Experiment	Site C1	Site C2	Mortality	Site differences
Free-ranging	W < H	W < H	C1 < C2	
Enclosure expt. I	W = H	W = H	C1 < C2	
Enclosure expt. II	W = H	W = H	C1 < C2	
Tether expt. I	W < H	W < H	C1 = C2	
Tether expt. II	W = H	—	—	
Growth free-ranging				
summer (PI)	W > H	W > H	W > H	W > H
fall (PII)	W > H	W > H	C1 < C2	C1 = C2
winter (PIII)	C1 < C2			
Enclosure expt. I	W > H	W > H (PI)	W = H (PII)	C1 < C2
Enclosure expt. II	W > H	W = H	W: C1 > C2	H: C1 = C2
Tether expt. I	W > H	W > H	C1 < C2	

than C2 is that juvenile conch realize density-dependent protection from predation. *Strombus* species often live in aggregations (Catterall and Poiner, 1983; Stoner et al., 1993), and recent experiments have shown that juvenile queen conch actually increase their survivorship by living in densities sufficiently high to compromise growth rate in certain cases (Stoner and Ray, 1993; Ray and Stoner, 1994). This aggregation or "herding" behavior probably reduces predation by providing a "probability refuge" (Bertram, 1978; Pulliam and Caraco, 1984); that is, the effects of predators are diluted by the presence of large numbers of alternative prey. Gregariousness provides an explanation for repeated movements of tagged conch from release site C2 toward C1, which was centered in a known juvenile aggregation. Stoner and Ray (1993) observed a similar response in queen conch translocated at another site near Lee Stocking Island. High growth rates were found outside an aggregation, but mortality was high, and movements were always toward the center of the aggregation. Regardless of the exact mechanisms involved, it is clear that both density and absolute numbers of conch released may be critical factors in an equation for success in stock enhancement. Typical nursery aggregations in the Exuma Cays range in size from less than 100,000 to several million juvenile conch (Wicklund et al.,1991; Stoner, unpubl. data). We speculate that releases at individual sites will need to be made with tens of thousands of conch; however, new research should be designed to determine the optimal number that can be released in an area, and how releases at several sites instead of just one or two might improve the probability of stock enhancement.

In this study there was no significant effect of density on growth rate over the ranges tested (0.5 and 2.5 conch·m^{-2}); however, inverse density-dependent growth was observed in another study at the same site (C1) with conch densities ranging from 1.0 to 4.0 conch·m^{-2} (Stoner, 1989b). It is not surprising therefore, that juvenile aggregations in the Exuma Cays are normally found with less than 2.0 conch·m^{-2} (Stoner et al., 1993). Such values are probably site specific. For example, at least one long-term nursery site near Lee Stocking Island rarely has more than 0.2 conch·m^{-2} (Stoner, unpubl. data). Stocking density will need to be evaluated carefully.

Different kinds of testing

General patterns of growth and mortality between the two stock types and the two outplant sites were relatively consistent among three kinds of experiments (free-ranging conch, enclosures, and tethers) (Table 11); however, the actual values measured were undoubtedly influenced by different manipulations. For example, recovery of free-ranging conch during the first two months of the experiment ranged from only 19 to 52%, whereas during the same period 70–95% survival was observed in enclosures. The coverless enclosures apparently excluded some important predators (such as the tulip snail, *Fasciolaria tulipa*), and not all free-ranging survivors were recovered. High mortality of conch on tethers at site C2 was probably a result of the low density of conch surrounding the tethers, lack of protection provided by enclosures, and reduced ability to avoid predators. Where the density of ambient conch was high (site C1), mortality rates in enclosures and on tethers were nearly identical, suggesting the significance of alternative prey, already discussed.

Comparisons of growth rates among experimental treatments in this study are difficult to make because of different times and durations of the growth periods. For example, high growth rates in free-ranging conch calculated for April to September 1990 reflect the high temperature season. Best comparisons are provided by enclosure and tether experiments run concurrently between April and June 1990, and by growth rates for free-ranging and enclosed conch measured between December 1990 and February 1991. In both cases the conch had relatively similar growth rates within stock type and site, suggesting that caging and tethering did not affect the nutritional state of experimental animals.

Given potential artifacts of enclosures and tethers on survivorship, measurements made on free-ranging conch will be preferred for certain questions, particularly those related to behavioral patterns and natural mortality (as opposed to relative mortality measured with tethers). On the other hand, it is impossible to recover all free-ranging conch and tag recovery can not be translated directly into survivorship. Mark-recapture data can be used to estimate population changes, with certain inherent limitations (Skalski and Robson, 1992); this may be a good approach for those primarily concerned with survivorship in large outplants. Those more interested in the role of habitat, stocking densities, and mechanisms of mortality will probably wish to maintain more control over the experimental animals. Covered enclosures, such as those used by Ray and Stoner (in press), offer the best means for testing growth potential in different habitats; meanwhile tethers give good information on relative rates of mortality for comparison of different sites, conch sizes or types.

Conclusions

One of the most striking implications of Appeldoorn's (1988) estimates of natural mortality in queen conch, is that juvenile mortality is very high. For example, survivorship in the first two years of life (to approx. 130 mm SL) may be as low as 35%. Our results on recovery of free-ranging wild conch over a 7–month period corroborate Appeldoorn's calculations. One may conclude from such survivorship curves that it will take a very large number of seed conch to enhance a local stock size. The problem would be exacerbated by poor seed stock quality, releases in suboptimal habitats, or release procedures which place the conch at unusual disadvantage (e.g. poor handling and acclimation, season of release, stocking density, and seed stock size).

Success in enhancing molluscan populations with hatchery-reared stocks has been variable. For example, Tegner and Butler (1985) recovered only 1% of their outplanted red abalone, *Haliotis rufescens*, one year after release. With the same species, Ebert (1989) reported high growth coupled with modest survivorship and some individuals reached sexual maturity with ripe gonads. In Japan, considerable success has been documented with the ezo abalone, *Haliotis discus lannai* (Saito, 1984). Hatchery-reared bay scallops, *Argopecten irradians,* released into the field at 20 mm were all lost within a month in one year; however, in another year the scallops lived to reproduce (Tettelbach and Wenczel, 1991). Despite failures, success is usually achieved as a result of adequate research. Stock rehabilitation via aquaculture may be the only viable means of restoring populations depleted to near-extinction levels, as is the case for queen conch in some regions of the Caribbean (Appeldoorn et al., 1987; Berg and Olsen, 1989).

Several steps will be required for restoration of queen conch stocks in the field:

1 The quality of hatchery-reared stock must be high and consistent. Morphology, physiology, and behavior must be considered, and stock quality should be field tested before major releases. Models of the effects of hatchery stock releases on a fishery (e.g. Madenijian et al., 1991; Polovina, 1991) will be useful only if hatchery-reared and wild stocks are identical in growth and mortality.

2 Sites for releases should be chosen with respect to information on historically significant nursery grounds, and preliminary tests for habitat suitability must be run with juvenile conch of the sizes to be seeded.

3 Release techniques must be developed to optimize conch survivorship. Factors which require further research are animal size, stocking density, minimum numbers to be released, release timing (season and time of day), and animal handling and acclimation. High numbers of individuals will need to be released given natural mortality rates and success might be improved by making releases at several sites.

4 Released conch and natural stocks will need to be managed in a comprehensive, multidisciplinary

plan for the nursery habitat, considering water quality, sediments, macrophytes, and predator species, as well as the conch populations themselves.

Hatchery techniques are well developed for queen conch, but the production of high numbers of juveniles does not insure the success of stock rehabilitation programs. Success will require much basic research on the life history and ecology of the species, particularly with respect to nutrition, growth, and predator-prey interactions. A close interaction between hatchery managers, fisheries biologists, and ecologists will be key to success.

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