

**Abstract.**—Habitat association, growth, and burrowing behavior were examined for a population of young-of-the-year juvenile queen conch, *Strombus gigas* L., in the southern Exuma Cays, Bahamas, during the winter 1988–1989. These early juveniles (35–54 mm siphonal shell length) primarily inhabit shallow unvegetated zones where they burrow in the sediment during the day and surface at night. Laboratory experiments showed that the burrowing rhythm was endogenous. Highest densities of 1- and 2-year-old juveniles (80–140 mm) conch were observed in adjacent, deeper seagrass beds, suggesting that queen conch make an ontogenetic shift in habitat. Results of an enclosure experiment revealed that growth rates of early juvenile conch were higher in seagrass (0.11 mm/day) and in rubble (0.09 mm/day) than in bare sand (0.01 mm/day) where they were initially found. These observations suggest that emergence of juvenile conch and movement to vegetated habitats at 35–54 mm shell length is associated with changes in nutritional requirements. Changing habitat association with age may also be related to predator avoidance and burrowing capabilities. Habitat requirements of early juvenile conch are different from those of 1-year-old juveniles and stock enhancement programs will need to consider ontogenetic habitat shifts.

# Ontogenetic shift in habitat by early juvenile queen conch, *Strombus gigas*: patterns and potential mechanisms

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Declining populations of queen conch (*Strombus gigas* L.), usually attributed to overfishing, have been reported for numerous areas in the Caribbean region (Brownell and Stevely, 1981; Appeldoorn et al., 1987; Berg and Olsen, 1989). Hatchery production and field release of juvenile conch have been suggested as a means of restoring depleted stocks (Berg, 1976; Brownell, 1977; Davis and Hesse, 1983; Iversen et al., 1986) but release methods have not been perfected (Stoner, unpubl. data). Although survival in small juvenile conch is low in natural populations (Appeldoorn, 1984), mass rearing of large juveniles (1- and 2-years-old) is costly (Siddall, 1983) and releases will need to be made with 0+ year class conch. Unfortunately, pilot releases of small conch have resulted in very low survival (Appeldoorn and Ballantine, 1983; Siddall, 1983; Appeldoorn, 1985), probably because of the lack of ecological information on early stage juveniles and problems associated with the identification of suitable habitats (Iversen et al., 1986; Stoner and Sandt, 1991; Stoner, unpubl. data).

Despite high densities (1–2/m<sup>2</sup>) of 1- and 2-year old conch (80–140 mm shell length) in certain seagrass meadows (Alcolado, 1976; Weil and Laughlin, 1984; Stoner and Waite, 1990; Wicklund et al., 1991; Stoner et al., 1993), individuals less than

50–60 mm in shell length (called early juveniles in this study) have rarely been seen in the field. Iversen et al. (1986) suggested that these early juvenile conch probably spend a large part of their time buried in the sediment. Attempts have been made to find them using suction dredges (Iversen et al., 1987; Stoner, unpubl. data) but few early juveniles have been collected and, to date, no quantitative data exist.

An opportunity to gather information on the distributional ecology and behavior of early juvenile queen conch was provided by the fortuitous discovery of a 0+ year class population near Neighbor Cay, in the central Bahamas, in January 1989. The subsequent investigation was designed: 1) to quantify habitat-specific distribution and abundance patterns, 2) to examine habitat-specific growth rates, and 3) to examine burrowing behavior in relation to time of day and light cues. The findings are discussed in terms of stock rehabilitation and management.

## Study site

The distribution and behavior of early juvenile queen conch was investigated near the north shore of

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Neighbor Cay in the southern Exuma Cays, Bahamas ( $28^{\circ}48.84'N$ ,  $76^{\circ}11.9'W$ ) (Fig. 1). The study site was located between a section of shoreline beachrock and subtidal carbonate rubble to the east and a sand bar to the west which extended outward from the shoreline (Fig. 2). Tidal currents ran parallel to shore and increased from near zero at the shoreline to 50 cm/s or greater 200 m from shore. The tidal range was 1.0 m.

Distribution and abundance of conch was examined along a 110-m section of nearshore shallow habitat (0–1.9 m deep at mean low water). Several zones extending to 25 m offshore from the low water mark were identified (Fig. 2). Zone A was intertidal, between high and low water marks. Zone B consisted of the shallowest subtidal area extending from shore to the top of a steep surf berm (zone C). Zone D was a sparsely vegetated transition area between either zone C (stations 1–7) or zone B (stations 8–12), and zone E. Zones A through C were bare sand habitats. Zones E, F, and G were areas vegetated with turtlegrass, *Thalassia testudinum* König and small amounts of shoal grass, *Halodule wrightii* König (Table 1). Measurements and experiments in zone E were made 2.5 m from the in-shore edge of the seagrass (Fig. 2). Measurements in Zones F and G were made 10 and 20 m, respectively, from the seagrass edge. The rocky area to the east was a carbonate cobble covered with macroalgae including an abundant turf of the green algae *Cladophoropsis*

*membranacea* and *Batophora oerstedii*, along with clumps of the branched red algae *Laurencia obtusa*, *L. poitei*, and *Graciolaria compressa*. The adjacent seagrass area (zones E, F, G) is a known, long-term (>5 years) nursery habitat for queen conch (>1-yr-old) studied earlier by Stoner and Sandt (1991).

## Methods and material

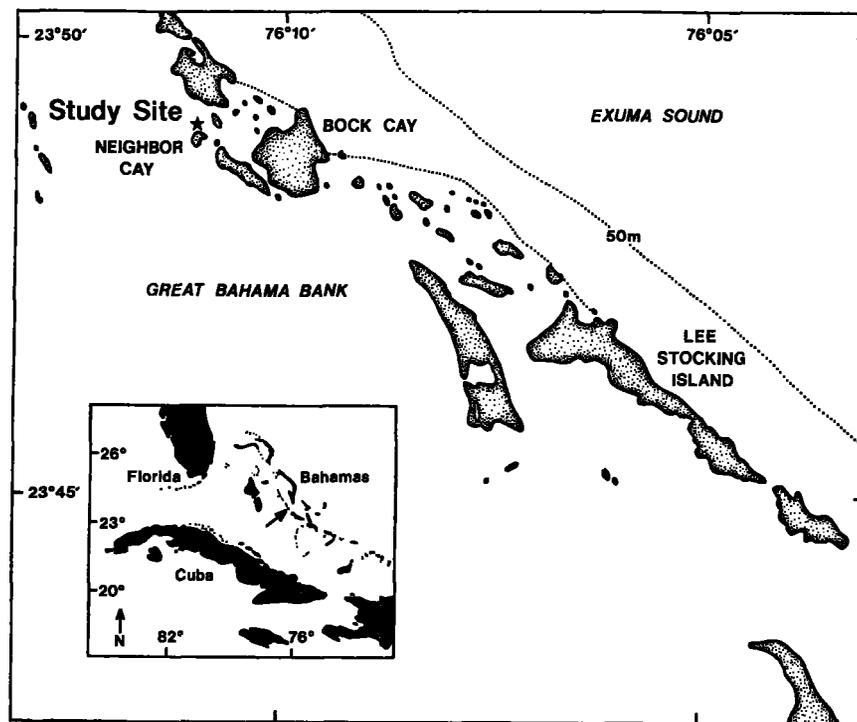
### Environmental measurements

Sediment grain-size and organic content, two factors frequently important in the distribution of infaunal animals, were measured in each zone (A to G) and along each transect perpendicular to the beach where possible (Fig. 2). Sediments to 5.0 cm depth were collected in a 40-mm diameter core and frozen ( $-15^{\circ}C$ ) until analysis. In the laboratory, one thawed sediment subsample of approximately 100 g wet weight was dried for at least 24 hours in an oven at  $80^{\circ}C$  to constant weight and incinerated at  $550^{\circ}C$  in a muffle furnace for 4 hours. Organic content was estimated as the percent difference between dry weight and ash-free dry weight. A second sediment subsample of approximately 50 g was used to measure granulometric properties. Grain-size for the sand fraction was determined by using standard sieve procedures (Folk, 1966), after removing salts and extracting the silt-clay fraction by washing with fresh-

water on a 62- $\mu$ m mesh screen. Silt-clay fractions were analysed with a standard pipet procedure (Galehouse, 1971). Product moment statistics were generated for mean grain-size (McBride, 1971).

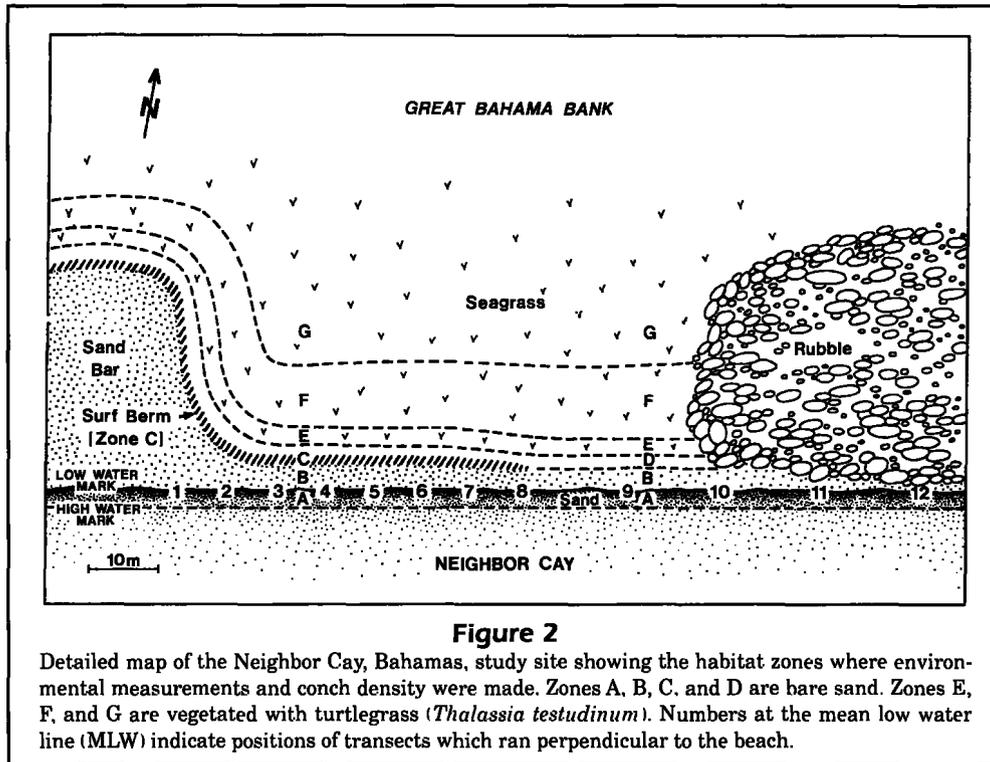
Relative cohesiveness of the sediment was measured in the field at every non-rocky station by using a 50-cm-long steel rod (15.3 mm diameter) equipped with a sliding lead weight (1.3 kg) and a stop 17 cm above the end of the device. The rod was placed vertically on the surface of the sediment, the weight was raised 25 cm on the steel shaft and dropped. Penetration was measured in mm, and the average of two measurements was recorded.

Seagrasses, macroscopic detritus (identified as being mostly senescent seagrass blades), and macroalgae were collected on transects 3, 5, 7, and 9 in the 3 vegetated zones E, F, and G. Samples were collected from a 25  $\times$  25 cm quadrat into 3-mm mesh bags. Detritus and



**Figure 1**

Map of the Lee Stocking Island area in the central Bahamas, showing the location of the Neighbor Cay study site where early juvenile queen conch were found.



above-ground parts of the macrophytes were separated by species and dried at 80°C for 24 hours. The individual components were weighed (0.1g) and biomass was expressed in g dry weight/m<sup>2</sup>. Water depth was measured at mean low water at every station in each zone.

**Conch distribution**

Conch density (no./m<sup>2</sup>) was determined in January 1989 at each station by searching two 0.75-m radius circles

(to 10 cm depth) to extract buried conch. Preliminary observations at the Neighbor Cay study site showed that burial depth was limited to 3–4 cm for 35–54 mm conch. All conch were counted and measured for shell length (SL, spire to siphonal groove).

In early February 1989, heavy mortality due to predation reduced the early juvenile population by at least 50%. Crushed shells of small conch were abundant in all of the primary habitats, and crabs were the suspected predators. Few free-ranging, tagged conch were found alive after that time.

**Table 1**

Habitat characteristics in seven zones (A–G) surveyed for early juvenile conch at Neighbor Cay, Bahamas (see Fig. 2).<sup>1</sup> Values are mean ±SD and number of measurements for each zone are in parentheses.

	A (12)	B (10)	C (8)	D (9)	E (10)	F (7)	G (7)
Depth	-0.2 ± 0.1	0.3 ± 0.1	0.7 ± 0.2	1.3 ± 0.4	1.4 ± 0.5	1.6 ± 0.1	1.9 ± 0.1
Sediments							
Grain-size	984 ± 116	974 ± 187	796 ± 250	705 ± 204	521 ± 90	490 ± 64	496 ± 64
Organics	2.59 ± 0.36	2.60 ± 0.28	2.62 ± 0.32	2.74 ± 0.22	2.73 ± 0.5	2.68 ± 0.26	2.70 ± 0.22
Relative cohesiveness	48 ± 7	48 ± 13	127 ± 35	47 ± 9	41 ± 7	40 ± 3	43 ± 6
Macrophyte biomass							
<i>Thalassia testudinum</i>	0	0	0	0	11.4 ± 5.6	8.8 ± 3.7	12.5 ± 4.0
<i>Halodule wrightii</i>	0	0	0	0	0.1 ± 0.2	0.1 ± 0.1	0.2 ± 0.3
Macrodetritus	0	0	0	0	4.8 ± 0.8	1.1 ± 0.6	1.3 ± 1.4

<sup>1</sup>Units for each characteristic are: depth (m at mean low water: MLW) (negative depth is height above MLW), sediment grain size (µm), sediment organics (% of dry weight), relative cohesiveness (mm), *Thalassia*, *Halodule*, and macrodetritus biomass (g dry weigh/m<sup>2</sup>).

## Enclosure experiment

Habitat-specific growth rates were examined experimentally in covered enclosures. Circular cages, 1.5 m in diameter (1.77 m<sup>2</sup>) were constructed with polyethylene mesh (1 × 1 cm) wired to a reinforcement bar driven into the sediment. Two cages were built in zone B, near transect 6 in bare sand, two were placed in the seagrass zone E, and two were built in the rocky zone between transect 11 and 12 (Fig. 2). The mesh was pushed into the sediment approximately 5.0 cm to prevent escape of conch. Tops of the cages were covered with the same plastic mesh to exclude predators.

Conch between 37 and 49 mm SL were collected in zone B. After removing all visible invertebrates from the 6 cages, 8 individually tagged and measured conch were randomly assigned to each cage. This yielded a density of 4.5 conch/m<sup>2</sup>, near the highest natural densities of similar size class conch in the field.

The experiment was initiated on 3 February 1989, examined after 19 and 41 days for cage damage and conch loss, and terminated after 63 days. Growth rates were expressed in mm shell length per day.

At the end of the enclosure experiment, conch were collected and frozen for measurement of body condition factor and stomach analysis. After thawing, the animals were drawn from their shells and rinsed to remove feces and mucus. All undamaged conch were blotted lightly and weighed (0.1 g). Condition factor was expressed as the ratio of soft tissue weight:shell length (g/mm). No significant sexual dimorphism occurs in queen conch until the gonads begin to develop at approximately 2 years of age; therefore, sex of the experimental animals was not considered.

Stomach contents, removed from the conch and preserved in a 70% solution of ethanol mixed with dilute rose bengal, were quantified by the gravimetric sieving method of Carr and Adams (1972). Pooled contents from the stomachs of conch from each experimental treatment were washed through a series of four sieves of decreasing mesh size (425, 250, 150, and 75 μm, and each sieve fraction was examined under a dissecting microscope (20–40×). Food items were heavily macerated but easily classified into general taxonomic categories; these included algae, detritus, and small invertebrates such as foraminiferans, gastropods, and polychaetes. The proportion of each food type (as well as sand) in each sieve fraction was estimated by identifying and counting the individual particles. After examination and identification, each sieve fraction was dried for 12 hours at 80°C. Dry weights of the fractions were summed and the relative importance of the different food categories were reported as the percentage of total dry weight.

Analysis of variance was used to test the significance of differences in growth and condition factor among the habitat treatments. Because multiple measurements from individual enclosures are pseudo-replicates (Hurlbert, 1984), mean values from the replicate cages were used in the analyses. Growth rates were log<sub>10</sub>-transformed to produce homogeneity in variance (Box test,  $F = 0.511$ ,  $P = 0.608$ ). Transformation was unnecessary for condition data. Tukey's test was used for multiple comparisons.

## Burrowing in the field

Early juvenile conch were first observed at Neighbor Cay late in the day (17:00 hours) on 8 January 1989, but none were visible the following morning. Assuming daytime burial, a survey of the population was initiated to examine diel periodicity in burrowing behavior. On 17 January, 64 early juveniles were tagged with vinyl orange spaghetti tags (Floy Tag & Manufacturing, Inc.) tied to the shell spire and released in zone B of the study site. A 4-cm free end was left on the tag so that buried conch could be easily seen and counted. During the survey, all early juvenile conch were tagged when observed (500 total).

Surveys for buried conch were made on 22 dates between 17 January and 28 February 1989. Between 17 January and 7 February, surveys were made by two divers swimming parallel to the beach. All tagged conch were counted and their behavior was recorded as either on the surface, or buried. Because massive mortality due to predation on early juveniles occurred during the first week of February, subsequent observations were made on the tagged conch held in experimental enclosures (see previous section). Over the course of the study the beach was surveyed at nearly all times of day and night and at different stages of the tide. Twice in January, surveys were made each half-hour during each of the transitions from dark to light and from light to dark. This permitted observations on the precise time of emergence and burrowing relative to times of twilight, sunrise, and sunset. Timing on 53 surveys was such that observations were made at least once or twice every half hour through day and night.

## Burrowing in the laboratory

The role of light stimulus on burrowing behavior of early juvenile conch was examined by subjecting them to different light-dark cycles in laboratory aquaria. Because most of the early juveniles found in the field had been manipulated during previous experiments, we

used hatchery-reared conch (39–53 mm SL) as subjects for this experiment.

Nine 190-L aquaria containing 5 cm of coarse sand from Neighbor Cay (zone B) were used in the experiments. Water temperature was maintained at approximately 28°C, and aeration was provided by under-gravel filters. Ten juvenile conch were placed in each of the aquaria and subjected to a schedule of 12 hours light:12 hours darkness. After 4 days, when the burrowing cycles of the animals became apparent, the animals were subjected to three different light regimes during the subsequent 4 days: three aquaria were kept under natural cycle (12:12), three were placed under continuous darkness and three under continuous light.

Observations on burrowing behavior were made twice during the day and twice during the night (0400, 1100, 1500, 0000 hours). Food, in the form of seagrass detritus, was placed on the surface of the sediment.

## Results

### Habitat characteristics

Transects from the intertidal beach to the shallow subtidal seagrass bed were characterized by increasing water depth ranging from -0.2 m (at MLW) in the center of intertidal zone A to 1.9 m in zone G. Sediment grain-size decreased with increasing depth (Table 1). In zones A through E sediments were coarse sands (984–521  $\mu\text{m}$ ), while medium sands (496–490  $\mu\text{m}$ ) were found in zones F and G. Organic content of the sediments varied little across the different zones, ranging from 2.59 to 2.74% of dry weight (Table 1). Sediment cohesiveness was relatively constant across the offshore zones (40–48 mm), except in the surf berm (zone C), where cohesiveness was low (i.e., penetrability and porosity were high) (Table 1).

Seagrasses, primarily *Thalassia testudinum*, were present in relatively low biomass in zones E, F, and G (Table 1). Dry weights of macrodetritus were also relatively low, with the highest mean value (4.8 g dry wt/ $\text{m}^2$ ) observed in zone E.

### Conch distribution

In the January survey, all conch found were less than 60 mm or greater than 80 mm SL. Given the summer spawning season of queen conch in the Exuma Cays (Stoner et al., 1992) and estimated growth, it was assumed that the former represented the young-of-the-year class (0+), while those larger than 80 mm were 1- and 2-year old conch. Eighty-six percent of the early juvenile conch (35–54 mm SL) were found in unvegetated zones B, C, and D (i.e., in the immediate

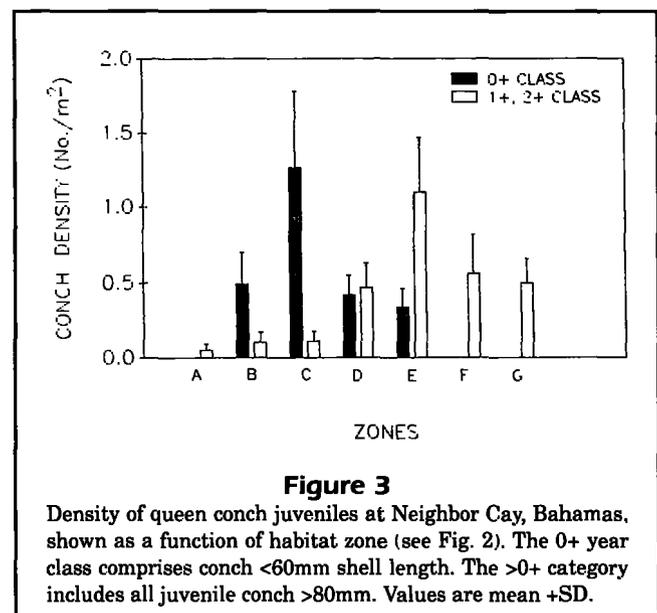
subtidal, in the surf berm, and at the bottom of the slope, respectively). All others were found in the vegetated zone E (Fig. 3). No early juvenile conch were found in the most offshore zones F and G. Mean density of early juveniles (1.25 conch/ $\text{m}^2$ ) was greatest in zone C, in association with the coarser grain sizes and low sediment cohesiveness (Table 1). In contrast to the narrow, high beach distribution of early juveniles, later stage juveniles were found in every zone, and highest densities in the seagrass zones E, F, and G (Fig. 3).

Most of the early juvenile conch were distributed between transects 3 and 9 (Fig. 2) over an area of approximately 250  $\text{m}^2$ . Based on a mean density of 1.25 conch/ $\text{m}^2$  in zone C and 4 conch/ $\text{m}^2$  observed in some areas of zone C, the early juvenile population was between 275 and 1000 conch. The densities observed probably accounted for most of the total population since 500 conch were tagged during night observations.

### Enclosure experiment

No mortality occurred during the first two periods of the transplant experiment; therefore, no replacements were necessary and growth rates were calculated for the original conch (Table 2). At the end of the experiment, two conch were found dead, one on sand and one on seagrass. Five conch were unaccounted for, two in the sand treatment, two in the rocky zone, and one in the seagrass habitat.

Growth rate in the sand habitat was much lower (0.012 mm/day) than the rates in seagrass (0.112 mm/day) and rock habitats (0.094 mm/day) (Table 2). The differences were significant (ANOVA,  $F = 769.35$ ,



**Table 2**

Daily growth rate in shell length and body condition factor<sup>1</sup> of early juvenile conch (37–49 mm shell length) held in enclosures on sand, seagrass, and rock habitats. Values are means  $\pm$ SD. Two enclosures with eight conch each were used in the analysis. Differences among treatments were different for both growth rate (ANOVA on log-transformed data,  $F = 769.35$ ,  $P < 0.001$ ) and condition factor (untransformed data,  $F = 12.82$ ,  $P = 0.034$ ). Letter codes indicate mean values which were not significantly different (Tukey's multiple comparison test,  $P > 0.05$ ).

	Treatment		
	Sand habitat	Seagrass habitat	Rock habitat
Growth rate (mm/day)	0.012 $\pm$ 0.001 <sup>a</sup>	0.112 $\pm$ 0.010 <sup>b</sup>	0.094 $\pm$ 0.002 <sup>b</sup>
Condition factor (g/mm)	0.027 $\pm$ 0.001 <sup>a</sup>	0.042 $\pm$ 0.002 <sup>b</sup>	0.039 $\pm$ 0.005 <sup>ab</sup>

<sup>1</sup>Condition factor is defined as the wet weight of soft tissue divided by shell length of an individual.

$P < 0.001$ ), and Tukey's multiple range test indicated that conch in sand grew at a rate lower than those in seagrass and rock habitats ( $P < 0.001$ ). Growth rates ( $P = 0.124$ ) for conch in seagrass and rock were the same.

Condition factor was also lower in the sand treatment (0.027), than in seagrass (0.042) and rock habitats (0.039) (Table 2). The habitat effects were significant (ANOVA,  $F = 12.82$ ,  $P = 0.034$ ). Differences in mean condition factor in seagrass and sand treatments were significant (Tukey's test,  $P = 0.035$ ), but the differences were not significant in sand and rock ( $P = 0.063$ ) or seagrass and rock ( $P = 0.648$ ).

Stomach contents of conch from the three different habitats were primarily algae and sand (Table 3). Conch enclosed in the rocky zone had a lower percentage of sand (26.5%) in their stomachs than conch in the other two habitats (48.6–58.2%); however, algae made up over 87% of the organic constituents of the stomach contents in all cases. Detritus particles, identified as *T. testudinum*, represented a small percentage of stomach contents of conch held in seagrass and rock habitats (Table 3). Foraminifera and Gastropoda found in the stomachs were small forms (<1 mm), probably taken incidentally with sand particles. The only polychaete found was *Spirorbis* sp., a small, sessile, tube-builder probably taken with epiphytic algae. Non-sand weight per stomach was highest for the conch in the rock habitat (Table 3).

## Burrowing experiments

Fewer than 30% of the early juveniles observed in the field were found on the surface during the day, whereas almost 100% were found on the surface at night (Fig. 4). Detailed observations near crepuscular hours showed that conch buried themselves before sunrise and surfaced before sunset. There was no indication of tidal rhythm on burrowing during our study.

Juvenile conch demonstrated lower percentages of burrowing in the laboratory than in the wild; but a marked rhythm in burrowing was observed during the four days of acclimation (Fig. 5). After light manipulations began, conch exposed to natural cycles of light (12 hours:12 hours) continued to emerge from the sediment in darkness hours (Fig. 5). Conch held in constant darkness demonstrated a much reduced frequency of burying themselves but this pattern became more erratic by the end of the experiment. Conversely, animals

held in constant light continued to show natural rhythms of activity (i.e., burying themselves and surfacing on the light-entrained schedule).

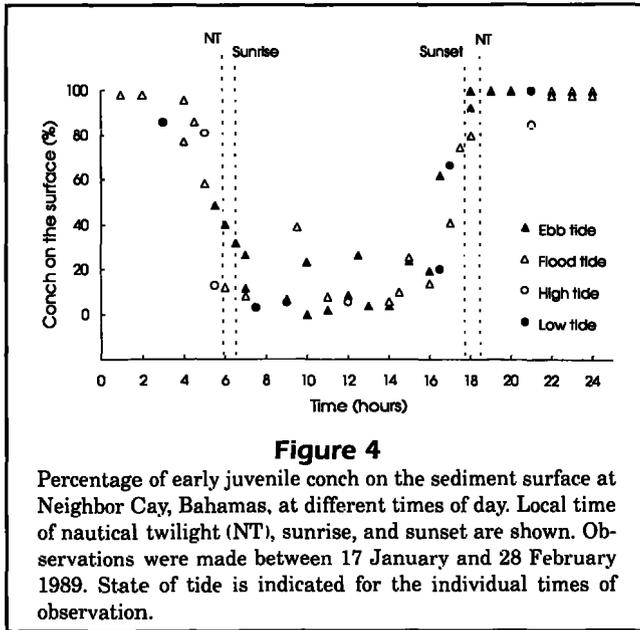
## Discussion

Queen conch less than 50 mm SL have rarely been observed on the sediment surface. Iversen et al. (1986) concluded that conch spend their first year of life buried in the sediment, after which time they are prima-

**Table 3**

Stomach contents of early juvenile conch (38–55 mm shell length) from the enclosure experiment. Individual components are expressed as the percent of dry stomach contents weight. Number of conch sampled from each habitat are in parentheses.

	Treatment		
	Sand habitat (12)	Seagrass habitat (15)	Rock habitat (10)
Sand (% of total weight)	58.2	48.6	26.5
Food Items (% of food weight)			
Algae	87.9	91.9	96.1
Foraminifera	10.5	7.5	2.1
Gastropoda	0.5	0.4	0.6
Polychaeta	1.1	0.0	0.4
Detritus	0.0	0.2	0.8
Food Weight (mg/individual)	7.0	9.0	15.5

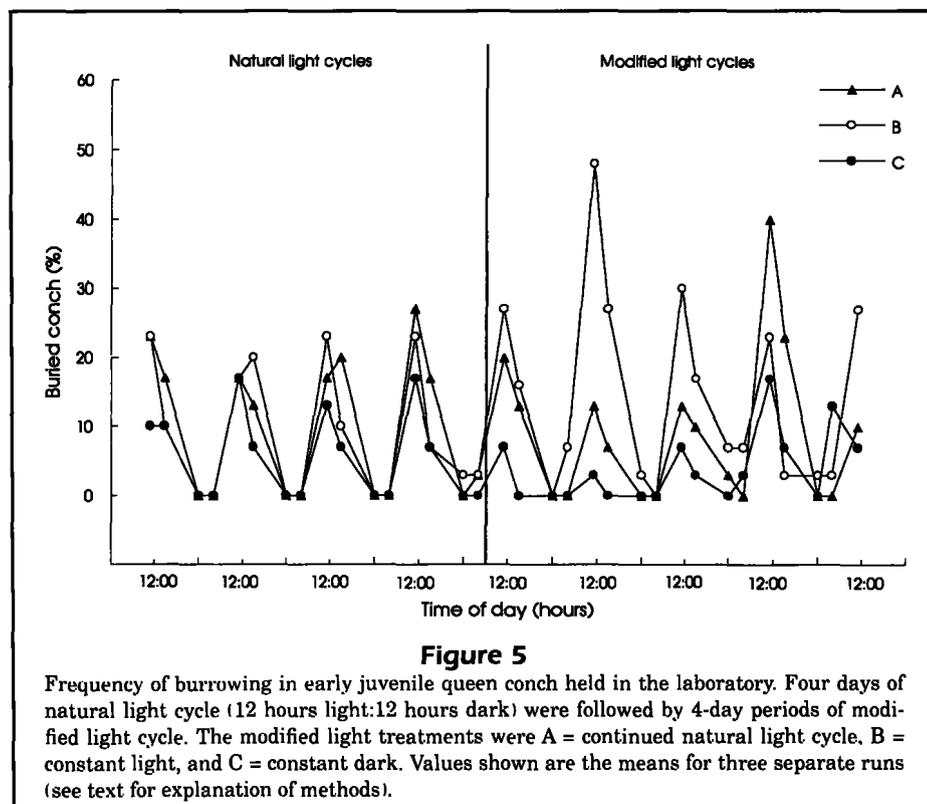


rily epifaunal. Our observations of burrowing rhythms in 35–54 mm queen conch at Neighbor Cay corroborate Randall's (1964) conclusion that early juvenile queen conch emerge from the sediment at night, but the extent to which smaller conch remain buried is unclear. Because early juvenile conch were never ob-

served between the summer spawning season and the January discovery of 35-mm conch, we hypothesized that burrowing progresses from full-time activity in conch less than approximately 25 or 30 mm until near continuous epifaunal existence in conch at approximately 1 year of age.

Early juvenile conch lack long spines and strong shells characteristic of older juveniles, and burrowing in shallow waters is probably a predator avoidance mechanism (Iversen et al., 1986, 1989). Laboratory experiments have shown that shell strength in queen conch increases rapidly with length above 55 mm (Jory and Iversen, 1988), similar to the size at which conch at Neighbor Cay became apparent on the sediment surface. Shell structure may also explain the typical age-specific type IV survival patterns observed in *Strombus gigas* and *S. costatus* (Appeldoorn, 1984). The significance of shell size and spination in providing protection from predators has been shown experimentally for other gastropods (Palmer, 1979).

Conch burrowing may also vary with age-related morphological constraints or with microhabitat features. For instance, burrowing abilities in queen conch may be reduced with increase in size and associated apical spination (Marshall, 1988). Also, low sediment cohesiveness probably facilitates burial. This may explain the high density of early juveniles in the surf berm at Neighbor Cay.



Early juvenile conch were not present in seagrass zones where 1- and 2-year-old conch were most abundant; this observation suggests that the distribution pattern was related to an ontogenetic shift in habitat rather than differential survivorship. Conch between 35 and 54 mm probably moved from sand to vegetated habitats to exploit higher algal concentrations. Stomach analysis indicated that algae are the primary dietary components for early juvenile conch at Neighbor Cay, similar to the diets of older individuals (Stoner and Waite, 1991). In sandy substrates, these foods probably become limiting as conch grow in size and food intake. This conclusion is supported by the results of our enclosure experiment which showed low growth for 37–49 mm conch held in the sand habitat. Growth rates were much higher in seagrass (0.11 mm/day) and rocky habitats (0.09 mm/day) than in sand (0.01 mm/day), and were similar to the rate (0.09 mm/day) observed in an earlier study of 1-year-old juveniles enclosed in seagrass at the same site (Stoner and Sandt, 1991).

Although early juvenile conch were normally buried during the day in the shallowest subtidal habitat and in sparse seagrass at Neighbor Cay, we have observed 12–25 mm conch on the surface in deeper seagrass beds with high shoot densities near Lee Stocking Island (Stoner, unpubl. data). Similar mention of epifaunal habits in early juveniles was made by Brownell (1977). It seems likely, therefore, that queen conch have different strategies of defense depending upon habitat. Conch recruiting to shallow sand habitats bury themselves in the substratum for protection from diurnal predators, and demonstrate strong, diurnal rhythms. Conversely, small conch inhabiting relatively dense seagrass beds find shelter among the seagrass blades. Burrowing would be inhibited by rhizome mats and anoxic sediments typical of seagrass beds with high biomass.

Although early juvenile conch appear to have considerable behavioral flexibility in avoiding predators, two lines of evidence suggest that early juveniles become less vulnerable to at least a certain suite of predators by the time they reach 50 or 60 mm SL. First, queen conch of approximately 60 mm have been the smallest individuals typically found on the surface during the day. Second, resistance to shell crushing is relatively low and constant up to 55 mm, then increases rapidly with conch size (Jory and Iversen, 1988). Thus, conch begin epifaunal existence once they are past the stage of highest vulnerability. As shown in our enclosure experiments, shallow sand bars probably become inadequate for juvenile conch by the time they reach 50 or 60 mm. Higher food intake, therefore, probably necessitates the move to vegetated habitats. However,

as observed at Neighbor Cay, mortality can be very high during the ontogenetic habitat shift.

The proportion of early juvenile conch inhabiting sand bars and seagrass habitats is unknown. Our conclusions on the importance of the sand or seagrass interface, or both, to conch growth and survival is supported by two lines of circumstantial evidence. First, Stoner and Waite (1990) reported increasing length frequency of 1+ year class queen conch from sand bars to adjacent seagrass habitats. Data reported here show that the age-specific trend continues into the 0+ year class and supports the significance of ontogenetic shift. Second, large-scale distributional patterns in 1+ year class queen conch in the Exuma Cays show that nearly all major nurseries are located in seagrass meadows immediately adjacent to coarse-grained, shallow sand bars or beaches (Stoner et al., 1993). The compromise between protection offered by infaunal existence and food availability on the sediment surface appears to be an important mechanism regulating the distribution and abundance of juvenile queen conch in the vicinity of Lee Stocking Island.

Successful stock enhancement with *Strombus gigas* will depend upon releasing young-of-the-year juveniles into suitable habitats (Siddall, 1983). Hatchery production of juvenile conch is now relatively well refined (Davis et al., 1987; Davis 1993), but release procedures are not (Stoner, unpubl. data). Given the high vulnerability of conch less than 50–60 mm, extreme care must be taken to insure placement of small conch for stock enhancement in habitats with adequate food and shelter from predators. Sediment characteristics will be particularly important in the site selection because of the normal burrowing activity of early juvenile stages. Sediments should have high porosity and be well oxygenated. Additionally, releases would best be made at night when the conch are normally on the sediment surface. It is clear from this study that the behavior and habitat requirements of early juveniles are different from those of 1-year-old conch and provision must be made for ontogenetic habitat shifts. Sand bars close to seagrass meadows probably provide the optimal habitat for early juvenile conch in the Bahamas.

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