BIOLOGICAL DATA ON BERRY ISLANDS (BAHAMAS) QUEEN CONCHS, *STROMBUS GIGAS*, WITH MARICULTURE AND FISHERIES MANAGEMENT IMPLICATIONS

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ABSTRACT

Biological data designed to assess the mariculture potential of queen conchs, *Strombus gigas*, and to aid in management of stocks in the Berry Islands, Bahamas, were collected from March 1980 to February 1983. Juveniles congregated in shallow areas adjacent to cays with strong currents. Growth of queen conchs differed among cays and seemed related to conch density. Average growth rates from several cays in the Berry Islands showed that growth was slower than that reported for queen conchs in other areas in the Caribbean. Estimated survival of juvenile queen conchs (about 10 cm) was 57-80% per month, or 2-9% annually. Yield per recruit from this population can be maximized by harvesting the animals at about 15 cm, which is the size at onset of lip formation but may be below the size at maturity. Presently, potential for increasing queen conch production through intensive and/or extensive mariculture seems low because of high hatchery costs, lack of dependable mass-rearing techniques, high predation on young released in nature, and slow growth of penned conchs.

The queen conch, *Strombus gigas*, a giant marine snail which is a major food resource in the Caribbean, Bahamas, and some Central American nations, has been exploited by subsistence and commercial fishermen for centuries. During the last several decades, recreational conch fisheries have developed and expanded considerably, placing high fishing pressure on these stocks. Until recently there has been little scientific research directed at improving production from existing stocks. The present study was designed to obtain biological data to fulfill this need in the Berry Islands, Bahamas.

Based on its high fecundity, feeding habits, limited migration habits, and high market demand, queen conch appears to be a desirable candidate for both intensive mariculture (enclosed) and extensive mariculture (released into nature to augment natural stocks) (Berg 1976; Brownell 1977; Brownell et al. 1976; Brownell and Stevely 1981). Success of either type of mariculture is dependent upon technical ability to mass-rear queen conch inexpensively from eggs on a dependable basis, and on knowledge of optimal natural habitats for raising juveniles to a sufficiently large size for either release in nature or for grow-out for market.

Our research on hatchery methods and potential of queen conch mariculture is described in Siddall (1983) and Iversen (1983), and the role of predators in limiting the size of conch populations is described in Jory (1982), Jory and Iversen (1983), and Iversen et al. 1986. Much of the information needed to assess feasibility of increasing queen conch production through mariculture is directly relevant to management of wild stocks. Specific objectives of the Berry Islands field work were to obtain data on age and growth, survival, and optimal habitat for rapid growth and high survival of early life stages. Based on this information, we make recommendations for management of wild stocks.

Our study area, the Berry Islands, lies on the northeastern edge of the Great Bahamas Bank (lat. 25°35′N, long 77°45′W) about 190 km east of Miami, FL (Fig. 1). This area is characterized by small cays, shallow sand flats (2-4 m deep) with abundant turtle grass, *Thalassia testudinium*, beds. The 30 plus islands are located on the west side of the N.E. Providence Channel and north of the Tongue of the Ocean. The islands are generally low-lying and covered with dense undergrowth, Australian pines, and palm trees. Tidal currents, frequently quite strong, set in and out of the openings between cays. Most cays are privately owned and sparsely populated.

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The habitat of the juvenile queen conch in our study area consisted of a large shallow plain surrounded by deep offshore waters. With a few exceptions, large adults were found in these deep areas and channels.

METHODS AND MATERIALS

Collections and observations were made at stations on adjacent cays: Little Whale Cay, Whale Cay, Vigilant Cay, Little Cockroach Cay, Bird Cay, Cat Cay, and Frazer's Hog Cay (Chub Cay) (Fig. 1). Twenty-three field trips were made to the Berry Islands from February 1980 through February 1983, each lasting 4-5 days.

The two methods used to obtain growth estimates were tagging-recapture and size-frequency analysis (Cassie 1954). After trying several different tags for conchs, we found that a thin plastic tag measuring 9.5 × 22.3 mm, obtained from the Floy[3] Tag Co. (Seattle, WA) was satisfactory. It was easily seen and suitable for even the small (ca 2-3 cm) conchs we tagged. A spot on the spire of conchs to be tagged was cleaned and dried, and the tag was affixed with underwater epoxy. We found these tags remained on wild conchs for about 2 years with indications of only a few being shed, of the 2,775 conchs we tagged and released at the sites mentioned above.

For growth estimates we measured queen conchs to the nearest mm along the anterior-posterior axis using a measuring board. Significant differences in growth rates of tagged conchs among cays and size classes were tested by analysis of variance. A Student-Neuman-Keuls test was used to detect significant differences. Differences were considered significant for all statistical tests at the $P = 0.05$ level. Mean values include 95% confidence intervals.

We derived whole animal weight-shell length relationships for queen conchs by measuring whole animal weight after removing conchs from their shells. We then removed everything but the foot to

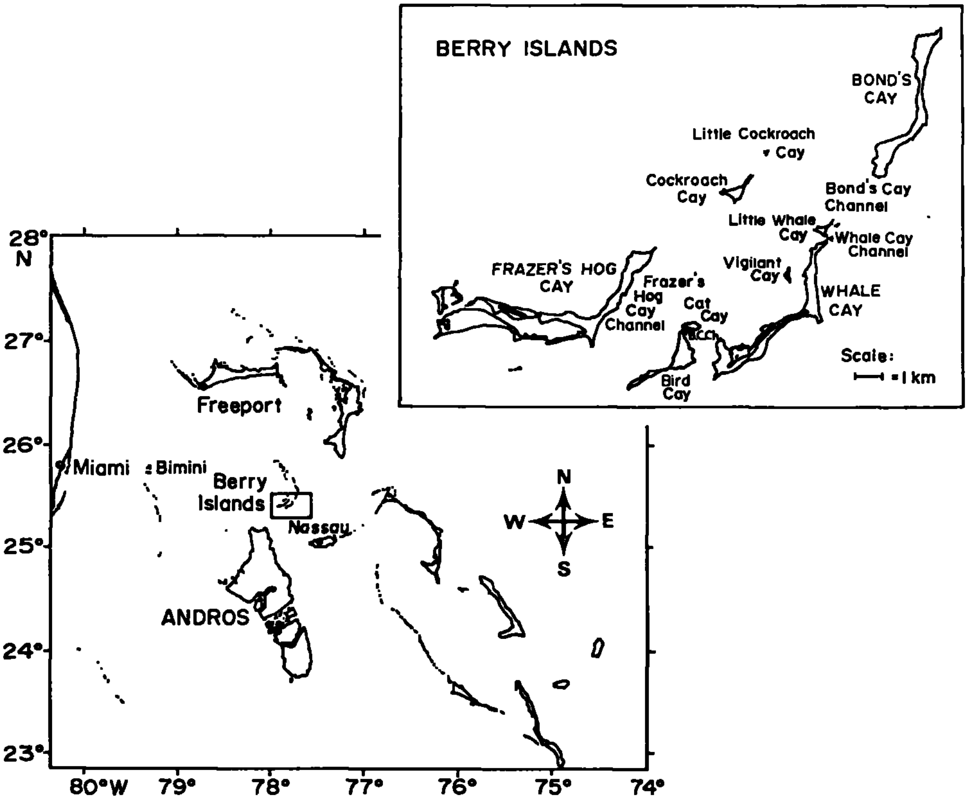

FIGURE 1.—Location of study site.

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[3] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

measure market weight. Significant differences in weight-length and whole animal weight-market weight relationships of conchs among cays were determined by analysis of covariance. Survival rates were obtained from the decrease in numbers of tagged queen conch at each of the tagging sites using Jackson's formula for monthly estimates and Heincke's formula for annual estimates as described in Everhart et al. (1975).

We used pens and cages of varying sizes to evaluate the feasibility of intensive mariculture. Six pens, each 25 m^2, were constructed with walls of monofilament webbing 30 cm high, held up by buoys. Pen walls were held in close contact with the bottom by heavy chains and stakes driven into the bottom, and were stocked with conchs 10-15 cm at densities of 1 or 2 conchs/m^2. Tagged conchs in this size range released in the vicinity of the pens served as controls.

Two additional large pens, 90 and 100 m^2 in area, were planted with 1 conch/m^2, the conch in the size range of 10-15 cm. Various studies on growth and survival in pens ran from 1 to 15 months.

Three wooden floating cages were used to measure growth and survival of small conchs (2-5 cm) over a 1-yr period. They were covered with fine NITEX 4 mm screening and measured 1 × 1 × 0.6 m, stocked with 50 conchs; 0.61 × 0.61 × 0.61 m, stocked with 10 conchs; and 1.6 × 1.2 × 0.6 m, stocked with 100 conchs.

Searches for small, young-of-the-year queen conch (<3 cm) were made by towing a dredge, by sieving sand samples with 4 mm mesh, by towing divers, by walking and digging on tide flats, by towing a shrimp try net (3 m opening and 1.3 cm stretched mesh), and by a suction dredge (Iversen et al. 1986).

To assess density of wild queen conch stocks in shallow water, counts were made along 100 m transects perpendicular and parallel to the shore. All queen conchs lying within 1 m of either side of the transect were counted. Significant differences in density of conchs among cays were tested by analysis of variance.

Most searches for queen conch were made during the day. To determine if this animal's burying activity varied between day and night, we conducted day-night counts at several cays and in our pens, and found no differential burying activity. Previous studies in the Virgin Islands (Randall 1964) and Puerto Rico (Appeldoorn and Ballantine 1983) reported no day-night differences in burying activity.

RESULTS AND DISCUSSION

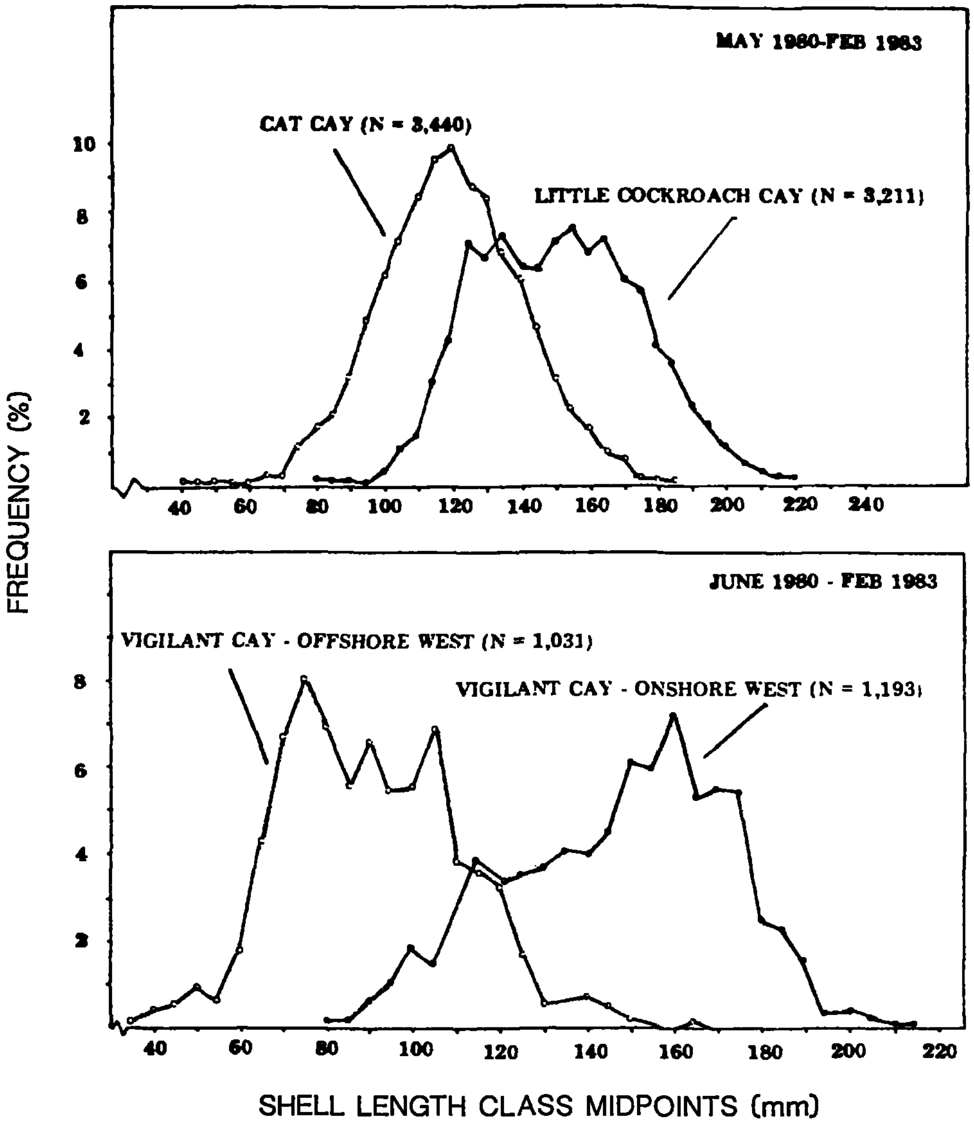
Queen Conch Distribution and Movement

Queen conchs sampled ranged from 2 to 26 cm in length (Fig. 2). The smallest conchs (<10 cm) were found on tidal flats, in shallow waters (<1 m), mostly on sandy bottoms with depressions. The largest juveniles were found in high concentrations near shores of cays, many exposed on low tides. Concentrations of adults with flared lips almost without exception were found in deep water (>3 m). Juveniles were found associated with cays having tidal flats, available food (microalgae and detritus), beaches with a gradual slope, and good water circulation. None was found in the large, open shallow-water areas between cays.

On all 23 field trips, young-of-the-year queen conchs were sought in the course of our regular field activities. The largest concentrations of young were found on the tidal flats between Bird Cay and Cat Cay (Iversen et al. 1986). Lack of shell epibionts on conchs and extensive searching suggested that small queen conchs live in the substrate and in rubble depressions until they are about 0.5 yr old, or about 3-5 cm long, at which time they are found on the tidal flats and nearshore areas in the Berry Islands. Size-frequency distributions (Table 1) showed that smallest individuals spawned the previous year (estimate based on laboratory-reared queen conchs by Siddall [1983], Brownell [1977], and others) appeared in winter, spring, and early summer.

Large juvenile queen conchs (10-18 cm) were easily located on the substrate surface all year long, generally in shallow water. Relatively few lipped queen conchs (N = 109; mean size = 19.3 ± 0.5 cm) were found during the study, most in channels 6 m deep although a few individuals were seen in shallow waters characteristic of most of our study sites. At least one lipped conch was recorded for all areas except Frazer's Hog Cay and Bird Cay-Cat Cay tidal flats. The smallest lipped conchs were found at Cat Cay ($\bar{X}$ = 14.8 ± 2.6 cm; N = 6). Lipped conchs were found every month except February, July, September, and December, with most found in April (N = 46) and October (N = 39). The distribution and seasonal occurrence of lipped conchs may reflect fishing pressure as much as potential reproductive activity.

Studies by Randall (1964), D'Asaro (1965), Brownell (1977), and Weil and Laughlin (1984) indicated that queen conchs have a protracted spawning season as long as March to October. Average length



of lipped conchs reported for the Virgin Islands was 20.4 cm (Randall 1964). Randall noted that lipped conchs sampled in the Berry Islands were smaller in length than conchs taken elsewhere in the Bahamas, or in the Virgin Islands.

Without exception, tagged queen conchs stayed at the cays where they were released, including transplanted queen conchs from nearby cays. It is possible that we did not observe migration because the majority of conchs we sampled were juveniles. Hesse (1979) reported that adult queen conch in Turks and Caicos ranged farthest (about 2 km) from the tagging site and made seasonal migrations offshore in fall and inshore in spring, while juveniles moved <1 km. Weil and Laughlin (1984) reported similar movements for adult and juvenile queen conchs in Venezuela.

Queen Conch Density by Areas

Since the density of queen conch in local areas can affect growth (Alcolado 1976; Weil and Laughlin 1984; Appeldoorn and Sanders 1984), we made density estimates at each of our sampling sites. The mean density of queen conchs at all locations studied, based on 100 m transects taken perpendicular to shore, was $\bar{X} = 7.9 \pm 1.2$ conchs/10 m^2. Highest mean densities were found at Bird Cay

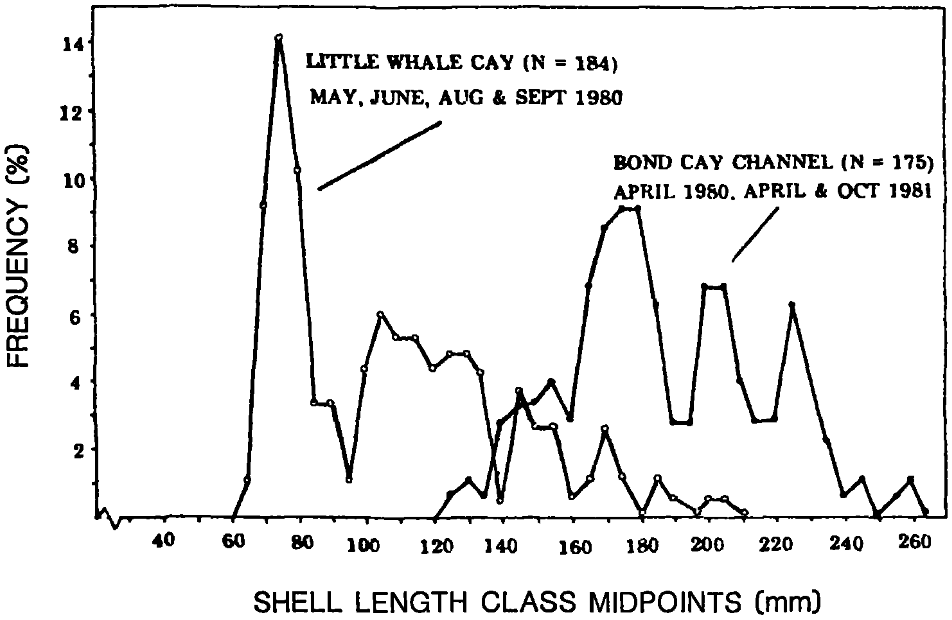


FIGURE 2.—Shell length distribution of queen conchs in the Berry Islands.

TABLE 1.—Size-frequency distribution of queen conch at Little Cockroach Cay (May 1980-April 1981).

Length (cm)	1980								1981			
	May	June	July[1]	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.[1]	Mar.	Apr.
8.0-9.0	1										2	
9.0-9.9	1											1
10.0-10.9	7	3						1	6		3	2
11.0-11.9	7	7		2				10	18		16	16
12.0-12.9	31	16		4	1			18	45		54	36
13.0-13.9	32	27		14	5	5	1	8	25		58	34
14.0-14.9	35	25		25	12	11	5	7	12		19	20
15.0-15.9	54	34		32	17	27	17	11	13		16	6
16.0-16.9	66	42		48	24	21	15	7	9		11	5
17.0-17.9	37	34		45	25	36	27	5	4		2	4
18.0-18.9	8	8		35	22	44	36	2	3		4	3
19.0-19.9	3	2		9	19	22	18	2	1		1	2
20.0-20.9				2	3	8	15	3	3		2	2
21.0-21.9				1		3	3		1		1	
Totals	282	198		217	128	177	137	74	140		189	131
Lipped conchs	0	0		1	0	1	3	0	1		0	0

[1] No data.

Channel, $\bar{X}$ = 19.6 ± 2.6 conchs/10 m^2, followed by Vigilant Cay west, $\bar{X}$ = 13.5 ± 3.1 conchs/10 m^2, and Vigilant Cay east, $\bar{X}$ = 12.2 ± 2.9 conchs/10 m^2. Lowest mean densities were found at Little Cockroach Cay, $\bar{X}$ = 1.5 ± 0.7 conchs/10 m^2 and Little Whale Cay north, $\bar{X}$ = 3.3 ± 0.7 conchs/10 m^2 (Table 2).

The mean queen conch density for all locations combined varied between June, September, and November. Density was highest in June ($\bar{X}$ = 9.9 ± 0.3 conchs/10 m^2, N = 978) followed by November ($\bar{X}$ = 6.7 ± 0.4 conchs/10 m^2, N = 673) and September ($\bar{X}$ = 6.0 ± 0.3 conchs/10 m^2; N = 722).

Queen conchs were randomly distributed over the 100 m transect at all locations except Cat Cay and Vigilant Cay, according to the results of a serial randomness test (Zar 1974). Conchs were especially clumped at Cat Cay, all appearing within 10 m of shore, effectively making their densities much higher than were reported for 100 m transects (Table 2).

TABLE 2.—Average density of queen conchs by sampling sites.

Sampling site	Average density (conchs/10 m^2 ± 95% C.I.)	N
Little Cockroach Cay	1.5 ± 0.7	88
Little Whale Cay (North)	3.3 ± 0.7	66
Vigilant Cay (West)	13.5 ± 3.1	808
Vigilant Cay (East)	12.2 ± 2.9	733
Bird Cay Channel	19.6 ± 2.6	391
Cat Cay (North)	4.2 ± 1.2	249
Cat Cay (East)	6.2 ± 3.3	372
Whale Cay	6.2 ± 1.7	123

Queen conch densities reported for other areas in the Caribbean were generally lower, ranging from 0.8-5.2 conchs/10 m^2 in Cuba (Alcolado 1976), 0.01 conchs/10 m^2 in U.S. Virgin Islands (Wood and Olsen 1983), 0.9 conchs/10 m^2 in the Turks and Caicos (Hesse 1979) to 0.1-21 conchs/10 m^2 ($\bar{X}$ = 4.2 conchs/10 m^2) in Los Roques, Venezuela (Weil and Laughlin 1984).

Growth of Queen Conch by Season, Location, and Size

Seasonal Growth

Based on all data collected between February 1980 and June 1982, there was a significant ($P < 0.001$ ANOVA) seasonal difference in mean length of untagged individuals. Queen conchs measured during winter were smaller than those measured during other seasons (Table 3).

TABLE 3.—Mean length of untagged queen conchs collected in each season between February 1980 and June 1982.

Season	Months	Mean length (cm)	N
Winter	December January February	11.9 ± [1]1.8	1,432
Spring	March April May	12.9 ± 1.1	3,475
Summer	June July August	12.6 ± 1.2	3,317
Fall	September October November	13.0 ± 1.3	2,943

[1] ±95% confidence interval.

Nearly all growth of juvenile queen conchs in our study took place during the warm summer months, May-September. At Cat Cay, for example, mean growth of tagged conchs ranged from 0.44 to 1.63 cm per month during the summer, and from 0.18 to 0.30 cm per month during the remainder of the year. This is consistent with studies by Randall (1964) on queen conch in St. Croix, U.S. Virgin Islands; by Alcolado (1976) in Cuba; and by Appeldoorn (1985) on small juveniles in Puerto Rico. Our small caged conchs (2.4-3.6 cm at tagging), held for 1 year, increased 3.56 cm on the average; 92% of this increase (3.27 cm) took place between April and October.

Growth by Location and Size

To examine the effect of location and size on growth, mean monthly growth of penned and unpenned tagged queen conch was compared within 3 size groups (<9.6 cm, 9.7-15.3 cm, >15.4 cm) by location. Densities of penned conchs (10-20 conchs/10 m^2) were higher than densities of unpenned conchs (2-20 conchs/10 m^2, $\bar{X}$ = 8) measured in the field. In every size class, unpenned conchs grew significantly faster ($P < 0.001$, ANOVA). Among unpenned conchs, there was a significant interaction effect of location and size on mean monthly growth. Large conchs (>15.4 cm) at Little Cockroach Cay, where density was lowest, grew faster than all other sizes. Small conchs (<9.6 cm) grew the next fastest, followed by intermediate-sized conchs (Table 4). Queen conchs at Cat Cay and Vigilant Cay offshore west, where densities were higher, grew slower as

TABLE 4.—Comparison of mean monthly growth rates (cm) for unpenned queen conchs. Underlined locations indicate significant difference in monthly growth between locations as determined by Student-Newman-Keuls test.

Size class	Tagging locations		
9.6 cm	Vigilant Cay Offshore West	Little Whale Cay	Cat Cay
	(0.40) ± [1]0.3 N = 198	(0.48) ± 0.03 N = 13	(0.50) ± 0.04 N = 114
9.6-15.3 cm	Cat Cay	Little Whale Cay	Little Cockroach Cay
	(0.25) ± 0.02 N = 385	(0.40) ± 0.03 N = 186	(0.48) ± 0.02 N = 248
15.3 cm		Little Whale Cay	Little Cockroach Cay
		(0.31) ± 0.07 N = 23	(0.50) ± 0.03 N = 146

[1]95% confidence interval.

a group than queen conchs at Little Whale Cay and Little Cockroach Cay (Table 4). Alcolado (1976) also reported that queen conchs in Cuba grew slower in areas of high density (5.2 conchs/10 m^2) than in areas of low density (0.08 conchs/10 m^2). Appeldoorn and Sanders (1984) reported similar results in a laboratory experiment on small juvenile conchs.

There was no significant interaction effect between size and location on growth of penned queen conchs. Smallest conchs in cages grew fastest, followed by intermediate-sized conchs (Table 5). There were insufficient data for large penned conchs to estimate their mean monthly growth. Among the intermediate-sized conchs where density was known, mean monthly growth was highest in pens with the lowest density (0.1/10 m^2 compared with 0.2/10 m^2).

Randall's (1964) penned queen conchs (mean length 6.2 and 7.5 cm, range 5.2-8.0 cm; N = 25) grew slowly (0.26 cm/month), but these measurements were made during winter months. Pen size was not specified. In another experiment, Randall placed 16 tagged conchs (19.0-20.0 cm, $\bar{X}$ = 19.4 cm) in a "60 ft by 140 ft elliptical fenced area" during winter and reported average growth of 0.1 cm/month through April when the experiment was discontinued.

Growth rates for our larger penned conchs (mean length 10.3 cm) approximated Randall's rates (0.1 and 0.2 cm/month), even though our data were recorded throughout the year. Growth rates were higher for our smaller conchs (mean length = 4.6 cm; mean growth = 0.4 and 0.2 cm/month) than for larger conchs.

Length at Age

Estimates of length at ages 1-3 were obtained for Berry Islands queen conchs by length-frequency analysis (Cassie 1954) and by fitting the von Bertalanffy equation to tagging data. Distinct length modes of 634 queen conchs measured in October 1980 were present at 7.6, 12.5, and 17.0 cm, suggesting length at ages 1, 2, and 3, respectively.

Parameters in the von Bertalanffy (1938) equation were estimated by fitting a Walford (1946) line to tagging data from Cat Cay, Vigilant Cay, Little Whale Cay, and Little Cockroach Cay (N = 117). Fitting a Walford growth line requires that the growth rate decreases with age. Since the largest queen conchs at Little Cockroach Cay grew faster than the middle-sized juveniles, we excluded these data from our calculations and obtained the following estimates of average length by ages (Table 6).

Age	*Lt (cm)*
I	8.3
II	12.2
III	15.4
IV	18.1

With L_∞ = 30.0
K = 0.20
t_0 = −0.65.

Our estimates of length at age from both length-frequency analyses and von Bertalanffy estimates of tagging data (excluding Little Cockroach Cay data) indicate that queen conch in the Berry Islands grow more slowly than those in the Virgin Islands and some of the areas in Cuba where density was low (0.8 conchs/10 m^2). We suggest that the higher densities of queen conch and cooler water temperatures in the Berry Islands may slow their growth relative to other areas.

Length-Weight Relationship

Whole animal weight(minus the shell)-shell length relationships were derived for queen conch sampled at Chub Cay (N = 39), Frazer's Hog Cay (N = 32), and Bird-Cat Cay Channel (N = 34). Log_{10}

TABLE 5.—Comparison of mean monthly growth rates (cm) for penned queen conch. Underlined locations indicate no significant difference in monthly growth between locations as determined by Student-Newman-Keuls test.

Size class	Tagging location						
9.6 cm	Pen 7	Pen 9	Small Wood Cage	Large Wood Cage			
	(0.04) ± [1]0.07 N = 25	(0.21) ± 0.06 N = 25	(0.24) ± 0.06 N = 38	(0.35) ± 0.06 N = 66			
9.7-15.3 cm	Pen 5	Pen 6	Pen 7	Pen 2	Pen 9	Pen 3	Pen 1
	(−0.05) ± 0.04 N = 38	(−0.01) ± 0.01 N = 38	(0.04) ± 0.02 N = 64	(0.08) ± 0.02 N = 48	(0.11) ± 0.04 N = 56	(0.15) ± 0.03 N = 45	(0.17) ± 0.05 N = 34
15.4 cm	Insufficient data						

[1] 95% confidence interval.

TABLE 6.—Estimates of queen conch length (cm) at age from the Caribbean.

Year class	Berry Islands,[1] Bahamas		Puerto Rico[2]	U.S. Virgin Islands		Cuba[5]	Venezuela[6]
	a	b		St. John[3]	St. Thomas[4]		
I	7.3	8.3	8.8	10.8	9.0	7.9-11.2	7.6
II	12.5	12.2	12.6	17.0	12.6	12.50-18.8	12.8
III	17.0	15.4	18.0	20.5	15.7	15.5-24.3	18.0
IV		18.1				17.4-28.3	
L (cm)		30.3		26.0		20.8-38.3	
K		0.20		0.52		0.287-0.571	
t_0		−0.65		0		−0.12-0.13	
N	634	103	193	104	301	63-284	161

[1] This study - size frequence (a) and von Bertalanffy fit to tagging data (b).
[2] Berg 1976 - size frequency.
[3] Berg 1976 and Brownell et al. 1976 - von Bertalanffy fit to Randall's (1964) tagging data.
[4] Wood and Olsen 1983 - size frequency.
[5] Alcolado 1976 - von Bertalanffy fit to tagging data from 7 locations.
[6] Brownell 1977 - size frequency.

(weight)-Log_{10} (length) relationships best fit the data. Analysis of covariance showed that queen conch at Frazer's Hog Cay and Chub Cay had similar whole animal weight-shell length relationships but that both differed from conchs at Bird-Cat Cay Channel. Therefore, two relationships were developed.

Frazer's Hog-Chub Cay

$$\text{Log}_{10}\ (\text{whole animal weight}) = -2.40 + 3.57 \times \text{Log}_{10}\ (\text{shell length})$$

$$r = 0.95 \qquad N = 71$$

Bird-Cat Cay Channel

$$\text{Log}_{10}\ (\text{whole animal weight}) = -1.36 + 2.84 \times \text{Log}_{10}\ (\text{shell length})$$

$$r = 0.93 \qquad N = 34.$$

Mean lengths of queen conch at Frazer's Hog Cay ($\bar{X} = 15.6 \pm 0.7$ cm) and Chub Cay ($\bar{X} = 18.6 \pm 0.8$ cm) were significantly ($P < 0.001$) larger than those at Bird-Cat Cay Channel ($\bar{X} = 13.6 \pm 0.1$ cm). Shell length-whole animal weight relationships changed with size. Smaller conchs ($\bar{X} = 13.6 \pm 0.1$ cm) increased in weight per unit length faster than did larger conchs ($\bar{X} = 17.0 \pm 0.7$ cm).

We found a close linear relationship between whole animal weight and meat weight of Berry Islands queen conch which did not vary among areas:

$$\text{market weight} = 0.65\ (\text{whole animal weight}) + 6.00$$

$$N = 105;\ r = 0.97.$$

The relationship between shell length and animal weight, although significant ($P < 0.001$) was not as close:

$$\text{market weight} = 11.47\ (\text{shell length}) - 50.69$$

$$N = 105;\quad r = 0.84.$$

Table 7 gives the numbers of different aged queen conchs in the Berry Islands needed for 1 pound of market meat. Using the whole animal weight-shell length and whole animal weight-market weight relationships developed above and assuming size at lip formation (14.8-19.3 cm) is the size at harvest, 4-10 queen conchs are needed to produce 1 pound of meat (Table 7). In the Berry Islands 6-8 conchs are needed to make 1 pound of market meat, as opposed to 2-3 and 3-4 conchs/pound from other areas in the Bahamas (Berg 1981). The high numbers of queen conchs per pound of market meat from the Berry Islands may be partially explained by their stunted growth.

TABLE 7.—Number of Berry Island queen conch required to make 1 pound of market meat.[1]

Age	von Bertalanffy estimated length at age	Whole animal weight/conch (g)	Market wt (lb)	No. of conchs to make 1 lb of meat
I	8.3	[2]17.8	0.04	26
II	12.2	[2]53.1	0.09	11
III	15.4	[3]73.0	0.12	9
IV	18.1	[3]130	0.20	5
IV[4]	19.3	164	0.25	4

[1] Market meat = (0.65) (whole animal weight − shell weight) + 6.
[2] Shell length (cm) converted to whole animal weight (gm) with Bird-Cat Cay Channel regression $\log_{10}$ (weight) = $-1.36 + 2.84 \log_{10}$ (shell length).
[3] Shell length (cm) converted to whole animal weight (g) with Frazer's Cay-Chub Cay regression $\log_{10}$ (weight) = $-2.40 + 3.57 \log_{10}$ (shell length).
[4] Mean size of lipped queen conchs sampled in Berry Islands.

Survival-Mortality

Estimates of monthly and annual survival of unpenned and penned queen conchs in the Berry Islands were derived from tagging studies. The estimates assume that tags are not overlooked, that tags do not fall off or affect survival, that the tagged population is similar to the untagged population in all other respects and that no emigration occurs during the experiments.

Monthly survival rate of unpenned queen conchs ranged from 57 to 80%, depending on location (Table 8). The estimates for Little Cockroach, Vigilant, and Cat Cays are the most reliable, because more conchs were tagged over a longer period of time at these three locations than at others. Annual survival was low for these areas, ranging from 2 to 9%. These proportions result in estimates of total instantaneous mortality rate, Z, from 2.41 to 3.91, considerably higher than those reported by Alcolado (1976) for queen conch in Cuba (annual survival 15-35%, Z from 1.06 to 1.90) or by Wood and Olsen (1983) for recruited queen conch in St. Thomas, U.S. Virgin Islands (Z from 0.22 to 1.80).

Appeldoorn (1985) found mortality of small juvenile queen conchs (<6.4 cm) in Puerto Rico higher at $Z = 8.62$, or an annual survival of 0.02%. In a recent study of large juveniles and adults, Appeldoorn (in press) estimated annual $Z = 2.67$, with M plus emigration $= 1.53$ and $F = 1.14$. Our survival estimates are probably low because of problems inherent to tagging studies mentioned above.

Survival of penned queen conchs in 4 of our pens was much higher than survival of unpenned animals (Table 8). Monthly survival ranged from 90 to 97% for penned animals, and annual survival ranged from 28 to 73%. However, all conchs died in the 2 deeper water pens. We attribute much of the increased survival rate of queen conch in our best pens to reduced predation, although an undetermined portion of the increase is due to eliminating emigration and the increased probability of finding tagged animals in an enclosure. However, the positive influence of increased survival must be balanced with the slow growth rates of all but the smaller (4.5-8 cm) sizes in pens.

Seasonality of burying, as demonstrated in our penned conch data and by Hesse (1979), using unpenned queen conch, can affect the estimated survival rate because some of the animals cannot be found. Based on our results in pens, the possible error in survival estimate due to burying would probably be relatively small because over about a 1-yr period, a total of 25 out of 200 queen conchs (about 12%) were buried; however, on any single monitoring trip only 1 or 2 individuals were buried.

Causes of Mortality

It is well documented that predation plays a significant role in the survival of queen conchs (Jory 1982; Jory and Iversen 1983; Iversen et al. 1986) and will not be detailed here. After settlement, at all sizes, even flared lipped, thick-shelled adults are subject to predation by large turtles and fishes; however, the rate of predation is significantly higher on the small, thin-shelled juveniles (2-5 cm) and decreases as the animals grow.

Based on our observations, those of our colleagues and reports in the literature, predation, rather than abiotic factors of the environment, or parasites and disease, seem to be the most important causes of queen conch mortality. Hence, stock size after settlement appears to be predator-controlled. This is not an unusual finding when the wide range of species of queen conch predators feeding on all sizes of conch is considered (Randall 1964; Jory and Iversen 1983; Iversen et al. 1986), together with the important role that predation plays in the mortality of many other mollusks (Jory et al. 1984).

TABLE 8.—Survival estimates for Berry Islands queen conchs.

	Unpenned conchs				Little Whale Cay penned conchs					
	Little Cockroach Cay	Vigilant Cay	Cat Cay	Little Whale Cay	Small wooden cage	Large wooden cage	Pen 1	Pen 2	Pen 3[1]	Pen 4
Monthly survival[2]	0.80	0.72	0.80	0.57	0.96	—	0.93	0.97	0.92	0.90
Annual survival[3]	0.02	0.09	0.09	0.02	0.69	0.13	0.36	0.73	0.36	0.28
Number tagged conch released	282	169	418	59	26	15	25	30	50	25
$\bar{X}$ size (cm)	15.0	8.4	11.4	13.0	7.2	7.6	10.5	10.2	10.2	10.5
Range (cm)	8.2-22.3	6.5-11.7	8.1-19.1	8.6-20.6	5.0-8.0	4.5-9.0	8.5-12.0	6.0-12.5	6.0-12.0	8.5-12.5

[1] Only 11 months involved.

[2] Monthly survival estimates made using Jackson's formula.

[3] Annual survival estimates made using Heincke's formula.

Management Implications: Yield per Recruit

Yield-per-recruit analysis, based on our estimate of the von Bertalanffy growth equation and total mortality from tagging, was conducted for the shallow-water queen conch populations in the southern Berry Islands. Yield per recruit was computed from the model given by Beverton and Holt (1957) which assumes that growth rate, susceptibility to capture, and natural mortality remain constant after age of recruitment.

We believe that the combined data from unpenned queen conch in all areas (excluding Little Cockroach Cay) gave us accurate estimates of growth and mortality. We estimated maximum meat weight for Berry Island conchs to be 463 g, based on the shell length to whole animal weight regression from the Frazer's Hog Cay-Chub Cay area, which was the largest sample. Age at recruitment was assumed to be 3 years (corresponding to a length of 15.4 cm). Maximum age of queen conch, based on L_∞ = 30.3 cm and our von Bertalanffy equation, was 11 years.

Using an overall mean annual survival of 7%, Z is 2.66. Estimates of yield per recruit were obtained for a range of values of M between 0.50 and 2.6. F varied between 0.16 and 2.66, by increments of 0.50, and t_0 varied between 1 and 5 years by increments of 1.10 for each level of M. This analysis probably encompassed any value of M and F that actually existed during the study.

At $M = 0.50$, age liable to capture that maximizes yield in weight per recruit is 3 years, over a range of F from 0.16 to 2.66. Thus, if fishermen take queen conch of approximately 15 cm and larger, they would maximize the yield available from the population. At all values of M above 0.50, results indicate a stage of underfishing because yield in weight per recruit increases over the range of F and decreases with increasing age liable to capture.

The results of yield-per-recruit analyses are limited for several reasons. First, larger, faster growing queen conchs from Little Cockroach Cay were excluded from the analyses; the von Bertalanffy equation did not describe well the growth of conchs from the full data set. Second, the range of sizes in the tagging studies did not accurately reflect the range of sizes in the total queen conch population in the southern Berry Islands. Most data were collected on immature conchs (before lip formation) that were living on shallow flats near islands. While the purpose of analyzing prospects for mariculture were adequately fulfilled by these data, they should not be used for fisheries management because they, for the most part, do not include the larger adults found in deeper channels between cays.

While these data are preliminary, they indicate an important management principle that was also determined for queen conch in the U.S. Virgin Islands by Wood and Olsen (1983); namely, that maximum yield per recruit is obtained at age of first harvest, which is just at onset of lip formation. In the Virgin Islands they found the maximum yield could be obtained by harvest between 3 and 5 years, at an average length of 15.78-19.1 cm. Maximum yield per recruit may occur below onset of maturity, however, since there is some evidence that queen conch may not be reproductively active until some time after lip formation (Wilkins et al., in press).

Mariculture Potential

Queen conch mariculture potential, one objective of this study, was investigated as a possible means to increase conch production in the Bahamas. A hatchery was established at the University of Miami. Techniques were developed for mass-rearing queen conch from egg masses collected in the wild through the larval stages (Siddall 1983). However, because of the high hatchery costs and high mortality associated with planting young mollusks in the wild (Iversen et al 1986; Jory et al. 1986), supplementing natural conch stocks by extensive mariculture does not appear to be economically feasible at this time. We placed juvenile conchs in pens at densities slightly higher than those in nature and found very slow growth, meanwhile experiencing considerable difficulty in physically maintaining the pens. Further, complete mortalities occurred in some pens, which we cannot explain.

Our results suggest that, for the numbers of queen conch required for supplementing natural stocks, the techniques available could probably only be successful in certain well-protected areas. In Bonaire, a degree of success has been reported by Hensen (1983). For intensive mariculture, unless a special area is found with good water exchange, natural food availability, where most predators can be excluded, and large juvenile conchs released, this technique of attempting to enhance production does not appear to have much potential at this time. With additional research, particularly on developing dependable hatchery techniques and cost-efficient means of predator protection, intensive mariculture may some day play a useful role in increasing production.

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