Evidence of Survival Value Related to Burying Behavior in Queen Conch *Strombus gigas*

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Interest in queen conch *Strombus gigas* aquaculture and more efficient management of fished stocks has increased due to the declining catches of this species throughout its range (Brownell and Stevely 1981). Knowledge of conch survival is critical to the success of extensive and intensive aquaculture, and also to management of the exploited stocks. Information on survival, including predation rates during the period after larval conch have left the planktonic (drifting) stage and settled onto the bottom until the time they emerge and graze about on the bottom, is very limited.

Despite field searches conducted by numerous researchers in different areas, very few small conch (<1 year-old; ~5 cm in length) have been found in nature (Robertson 1959, Randall 1964, Hesse 1979, Davis and Hesse 1983). Research by Iversen et al. (1986) in the Berry Islands (Bahamas) using a variety of devices to sample the substrate and the substrate-water interface confirmed the paucity of young conch on or near the substrate surface in areas adjacent to aggregations of >1-year-old juveniles. It seems reasonable that these very young conch do not migrate over long distances to the cays where we find the large juveniles, but are carried during their planktonic life by currents to these locations. These findings suggest that conch may be buried almost continuously until they reach a shell length of ~5 cm.

The purpose of this study is to use tag-recapture data to examine the relationship between survival of juvenile conch and their burying activity.

Methods and materials

The data used in this study were collected in the Berry Islands (Bahamas) about 190 km east of Miami, Florida (Fig. 1). A wide range of conch sizes (3.5–22.0 cm) was tagged during these experiments at all seasons and at several different cays to account for the effects of different habitats, conch sizes, and seasonal variation.

The sampling area, consisting of shallow sand flats with abundant turtle grass *Thalassia testudinum*, is described in more detail by Iversen et al. (1987).

Individual conch were tagged with thin, numbered plastic tags affixed to the spire with underwater epoxy. Shell length was taken using a measuring board (Iversen et al. 1987). Shallow intertidal waters were sampled by wading and the deeper offshore water by snorkeling. Counts of tagged conch were made on 23 sampling trips lasting 4–5 days made approximately every 5 weeks between May 1980 and February 1983. A conch was considered to be buried when it was not found on one or more sampling trips, but was found alive on subsequent visits (Table 1). We believe this to be a reasonable assumption, because the aggregations of conch we studied remained in close proximity to the cays and when not buried were easily located. Conchs as large as 10–15 cm in length which we placed in 25-m^2 pens would bury and were not found on some visits despite intensive searching. On subsequent visits a month or more later, they would reappear on the surface of the substrate. For example, of 27 tagged conch in one pen, seven were buried on at least one visit between April and December 1980. Tagged individuals released at various cays that were not subsequently found were considered to have fallen prey to predators; large juveniles ($\gtrsim$16 cm) were assumed to have migrated offshore to deep water (Iversen et al. 1987).

Results

Our tagging data show a significant positive correlation (Fig. 2) between survival and percent buried for conch released in the subtidal region of about–2 m depth south of Vigilant Cay (shell length range, SLR, 3.5–16.5 cm; $r = 0.80$; $P<0.01$), and for conch from intertidal zones at Cat Cay (SLR 4.5–18.0 cm; $r = 0.56$; $P<0.05$) and Little Cockroach Cay (SLR 8.0–22.0 cm; $r = 0.81$; $P<0.05$).

Discussion

Predation is probably the most important cause of natural mortality on stocks of >1-year-old juvenile conch. Based on our searches for parasites in juveniles and adult conch, and our field observations, we do not believe that parasites or diseases play an important role in conch survival. There are reports of isolated mass mortalities of conch

Manuscript accepted 28 December 1989.
Fishery Bulletin, U.S. 88:383-387.

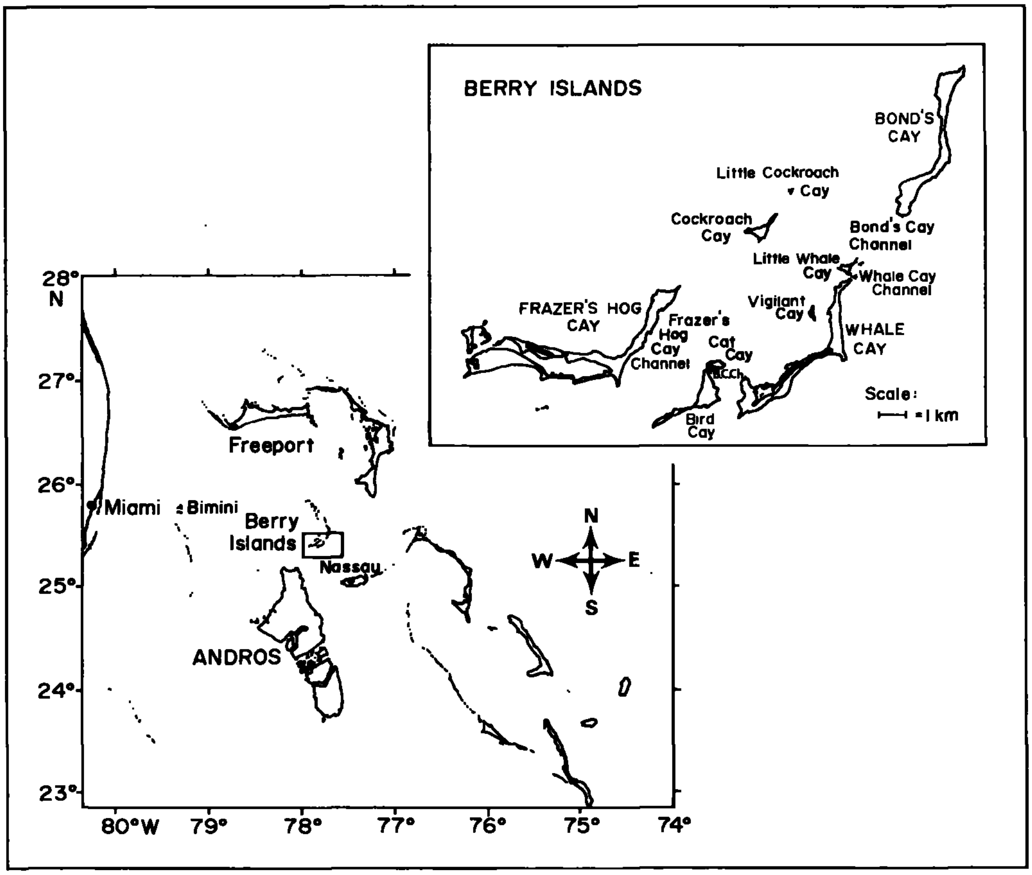

Figure 1
Location of *Strombus gigas* study site in the Berry Island (from Iversen et al. 1987).

Table 1
Example of database used in this study of queen conch burying behavior. Tagging location: Little Cockroach Cay, Berry Islands, Bahamas. Tagging date: 27 May 1980.

	Field observations								
	1980							1981	
Tag no.	05/27	06/23	08/21	09/05	10/03	11/01	12/16	01/23	03/03
0617	14.9	15.3	16.0	(B)	(B)	17.6			
0618	15.8	(B)	(B)	(B)	(B)	(B)	(B)	18.6	
0619	16.5	16.8	17.6						
0620	15.2	15.7	16.6	(B)	17.8				
0621	17.1	(B)	18.1	18.6	19.0				
0622	15.1	15.7	16.6	17.2	(B)	17.7			
0623	16.2	(B)	17.4	17.7	(B)	18.8			
0624	16.7	17.3							
0625	14.7	15.6	16.2	17.0	17.1				
0626	14.4	15.1	15.9	16.4	16.8				
0627	15.2	16.0	16.5	17.4	(B)	18.1			
0628	14.1	(B)	15.3	(B)	16.1	16.0			

A tagged conch is considered to be buried (B) if not found on one or more subsequent trips, but is eventually found. It is assumed to have been killed or to have migrated offshore if not subsequently found. No tags from this group (0617–0628) were found in the vicinity of Little Cockroach Cay during the period February 1981 to the end of the study, February 1983, despite 11 field searches made every 4–6 weeks during this period. Conch of about 18–20 cm shell length generally migrate into deep offshore waters from this cay (Iversen et al. 1987).

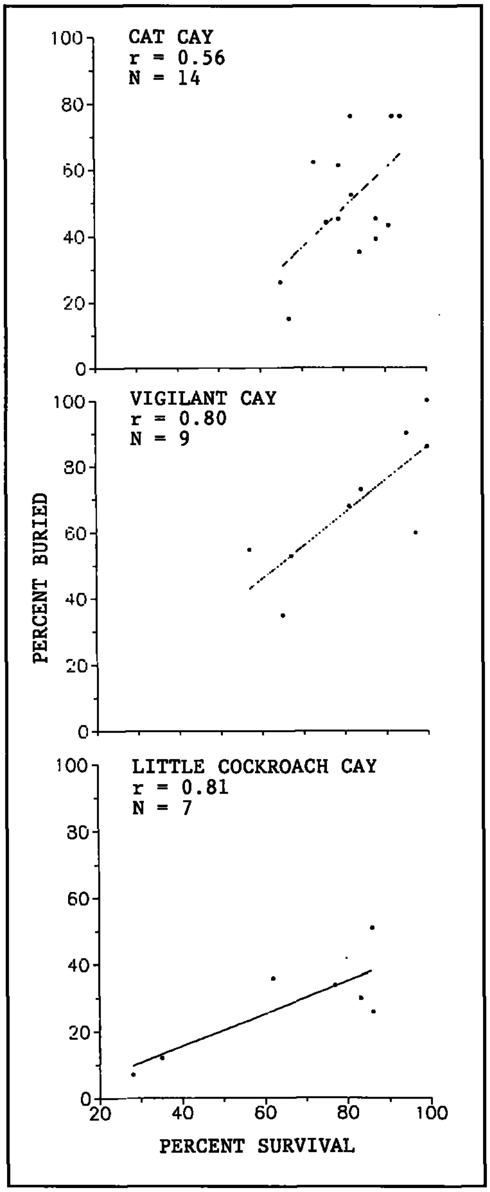

Figure 2

Relationship between *Strongus gigas* burying activity and survival. Vigilant Cay: offshore, 171 conch tagged 3 October 1980; SLR 6.7–9.3 cm. Cat Cay: 455 conch tagged 27 May 1980; SLR 8.9–19.1 cm. Little Cockroach Cay: 84 conch tagged 8 April 1981; SLR 9.2–15.5 cm. N = number of months the experiment lasted.

during the summer on tide flats when temperatures reached extremely high levels (Weil and Laughlin 1984).

In the few trials made to date, survival of hatchery-reared small conch (2.0–7.0 cm in length) released in different locations in the Bahamas and the Caribbean has been extremely low. For example, in St. Croix, Coulston et al. (1987) reported that unprotected juvenile conch did not survive. And in a small-scale preliminary trial, Iversen et al. (1986) reported complete mortality of 1.3–3.7 cm long, hatchery-reared conch placed under protective screens laid on the substrate and held in place by rocks.

To fully interpret our results and put them in context with what is known about mortality and predation in juvenile queen conch, it is necessary to consider the factors affecting both burying behavior and mortality/predation. Concerning the former, we first note that very small conch are almost never found unburied. Although emphasis of our research was on animals larger than 5 cm in length, we searched for small conch during all field trips. Of the 491 small conch (1–9 cm) we found, all but a few (~3%; $N = 15$) were buried, some as deep as 20 cm, while others were barely covered by broken shells and rubble in shallow depressions on a large tidal flat. With only a few exceptions, those found on the substrate were larger than ~5 cm.

Iversen et al. (1987) showed significant differences in burying activity within a tidal cycle at various sites in the Berry Islands. Significantly more conch buried on high tides than on low tides, which they suggested may be a response to possible increased predator activity during high tides when large swimming predators can reach the upper intertidal zone. This apparent tidal-height behavioral response should not be triggered in the deeper (subtidal) water offshore of Vigilant Cay where we released tagged conch. Our results showing a relationship between survival and burying behavior suggest that conch over a wide range of sizes are less vulnerable to predation when buried. This may explain why the highly vulnerable, thin-shelled young-of-year bury for extended periods.

In addition to the effects of conch size and tide stage, burying behavior may be affected by time of year (a proxy which encompasses a number of environmental circumstances, such as water temperature and wind and sea conditions). According to Hesse (1979), seasonal variation in burying behavior is also a factor, with more active burying during the winter when the waters are cooler and the winds stronger than during the remainder of the year. However, no clear-cut seasonal trend in burying activity is evident from our data. Rather, there are generally wide variations in the number of animals buried, which we believe are possibly related to different environmental conditions in the different habitats of the cays where we collected our data. Our size-frequency data suggest that burying activity is not related to the size of the animals, after they attain a shell length of ~5–6 cm.

With respect to mortality, Appeldoorn (1985) showed that juvenile queen conch mortality rates were highest during summer and lowest during winter in Puerto

Rico. Jory and Iversen (1983) found in their studies in the Berry Islands that the highest levels of predation occurred during the summer and the lowest during the winter. They also suggested that reduced mortality in the winter may be due to reduced predator activity and a decrease in conch activity.

Small conch do not grow in length during the winter period of burying (Appeldoorn 1985, Iversen et al. 1986). Therefore, when they emerge in the spring to begin active foraging on the substrate they would have gained no obvious "size" survival advantage as a result of their "hibernation." Johnson et al. (1964) demonstrated that the shell thickness of queen conch increases with activity, and because buried conch would not be expected to be very active during the winter, shell thickness would probably not increase substantially over this time.

Conch survival estimates show trends common to many mollusks: low survival for small animals, increasing as the size of the mollusk increases (Jory et al. 1984; Appeldoorn 1984, 1988; Iversen et al. 1986). Recoveries from 259 tagged wild conchs (SLR 5.0–21.0 cm) at Little Whale Cay, Bahamas, over a 6-month period showed a significant positive correlation between length at tagging and percent recovered ($r = 0.95$; $p<0.05$). This correlation suggests that within this size range mortality decreased with increased conch size. Using floating cages to provide protection from predators and increase survival, we demonstrated that as high as 96% survival was achieved for conch in the size range 5.0–8.0 cm over a 1-year period, while survival of tagged non-caged small conch of similar size after 6 months was only between 0 and 10%. Similar evidence on differential survival by conch size was gathered in Puerto Rico by Appeldoorn (1984) who, by using short-term (~8 weeks) mark-recapture data for both queen conch and milk conch (*S. costatus*), determined that larger individuals suffered less mortality than smaller ones. Jory and Iversen (1988) provided direct evidence of a lack of increase in shell thickness in small juveniles by examining the relationship between shell breaking strength and shell size of queen conch. They found little increase in breaking strength up to a size of ~5.5 cm, suggesting that queen conch shells are relatively thin below this length. Above ~5.5 cm, pressure to crush shells increased rapidly with increasing shell length.

As queen conch increase in size, their spines increase in length and become more robust. Spines may reduce predation on mollusks in various ways (Palmer 1979). They increase the overall size of the shell, thereby limiting predation to larger predators. Conch spines also distribute crushing pressure over a greater area of the shell, thus increasing the pressure required to crush the shell (Jory and Iversen 1988). Spines also serve as additional area for attachment of epibionts which may help conceal mollusks from predators (Feifarek 1987).

The amount of attached organisms on the shells of conch increases with the size of the conch, suggesting a decrease in long-term burying activity with increase in conch size (Iversen et al. 1986). All of the smallest conch we collected had very clean shells with no growth of attached organisms, in contrast to the rapid and heavy growth of algae we observed on the shells of similar-sized conch in hatchery tanks at the University of Miami laboratory and in floating cages at Little Whale Cay, Bahamas. These results further support the hypothesis that young conch spend most of their early life (up to ~1 year of age) below the surface of the substrate, a strategy that may provide haven from some predators (Hesse 1979, Appeldoorn 1985, Iversen et al. 1986).

The relationships between shell size and strength and between survival and burying have practical application in suggesting place and time of year to release hatchery-reared conchs, in order to both minimize predation and increase the efficiency of planting programs using hatchery-reared juveniles of queen conch and several other mollusk species. Placement of young hatchery-reared conch in relatively safe, natural areas optimal for burying and with certain physical characteristics such as strong currents, fine-to-coarse sand, and abundant intact and broken mollusc shells, where red and green algae and sponges occur (as described in Iversen et al. 1986) would obviate the need for overwintering in an expensive hatchery facility. Further, as suggested by Jory and Iversen (1983), fall planting of small hatchery-reared conch would provide time for them to acclimate to their environment before the spring or early summer "emergence." This is particularly relevant in view of evidence available for other mollusk species, where hatchery-reared juveniles are more vulnerable to predators when released in nature than wild juveniles (Tegner and Butler 1985). Development of an inexpensive enclosure for holding large numbers of young-of-the year under the surface of the substrate could further increase survival of hatchery-reared conch juveniles.

Acknowledgments

This research was funded jointly through the University of Miami by the Wallace Groves Aquaculture Foundation and the Kirby Foundation. This support is deeply appreciated as is the field assistance provided by many individuals. Employees on Little Whale Cay gave generously of their time and knowledge of the area.

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