

Field Release of Cultured Queen Conch In Puerto Rico: Implications for Stock Restoration

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ABSTRACT

Laboratory-reared queen conchs, *Strombus gigas*, between 20-50 mm in length were tagged with a colored streamer and released into the field in several short-termed experiments. Studies were designed to gain information about growth, survival and movements in different habitats. Sites studied were an offshore sand and algal plain, and a sheltered inshore sea grass bed.

Growth of released conchs was comparable or greater than for controls maintained in tanks. Survival was highly variable between experiments, rendering site comparisons meaningless. Shell fragments recovered from dead individuals indicated that crustaceans were the dominant predators.

Analysis of growth and mortality rates suggests that strong conservation measures will be required as a prerequisite for the restoration of conch populations.

As natural stocks of the queen conch, *Strombus gigas*, have declined throughout the Caribbean (Brownell and Stevely, 1981) interest in its mariculture potential and fisheries management have increased (Berg, 1981). Under consideration are both intensive and extensive mariculture, and the stocking of depleted areas with seed conchs.

The success of any stocking program will ultimately depend upon the relationship between growth and mortality subsequent to release. Hence, knowledge of these processes and the factors which affect them is essential. Among the most important influencing factors are: the size of conchs at release, the time of release and the characteristics of the release site.

In other marine species, mortality is known to be significantly higher during early juvenile stages, declining with age/size, until stabilizing about some constant rate (Brousseau, 1978; Saila and Lough, 1981). The period immediately following release can then be expected to be the most critical. Existing estimates for the rates of growth and survival of *S. gigas* in the field were obtained only from large juveniles and adults (Randall, 1964; Berg, 1976; Alcolado, 1976; Wefer and Killingley, 1980). Given the critical nature and variability of these processes during early juvenile stages, extrapolation of these rates can be misleading.

Experiments involving the field release of hatchery reared conchs (Ballantine and Appeldoorn, 1983) have recently been initiated. Their purpose is to study the growth, mortality, and movements of small juveniles and the factors influencing their rates. These experiments involved the release of both *S. gigas* and the closely related milk conch, *S. costatus*. The purpose here is to present the initial results obtained for *S. gigas*. Reference to *S. costatus* will be made only to substantiate or add to these observations.

METHODS

Tagging

All conchs were tagged by gluing a thin flexible plastic strip, 75 mm long, to the tip of the spire (cleaned and dried) using a cyanoacrylate based adhesive. Groups of conchs were coded by varying the color of the strip; bright fluorescent colors were used to enhance tag recognition. In later experiments each tag was individually

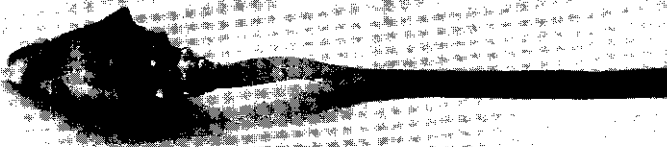


Figure 1. A 36 mm *Strombus gigas* with a 75 mm tag.

marked using a fine-tipped permanent marking pen (Fig. 1).

This method of tagging was chosen for the following reasons. The only way to locate small, predominately buried (see Results) conchs is to have a prominent, easily recognizable tag which remains exposed even when the conch itself is completely buried. If numbered, the tag can be read without disturbing the animal. Observations on tagged and untagged individuals held in a tank with a natural algal-sand-coral rubble bottom showed the tags to affect neither movement nor growth. Field observations showed the conchs to be unaffected by tag movement resulting from strong wave surge.

Tags apparently do not affect predation. Lobsters, *Panulirus argus*, placed in a natural bottom tank containing tagged and untagged conchs showed no preference between the two groups. The observations were consistent with the lobster's use of chemoreception for locating prey (Conklin, 1980). Lobsters were chosen for the experiment because they are a dominant component of the crustacean population thought to be responsible for the majority of conch predation (see Discussion).

Undisturbed, the tags will stay attached to the shell for a considerable period of time. One shell was recovered 6 months after release with the plastic still firmly attached, although this duration is felt to be somewhat beyond the average reliability of the tag. Attacks by predators may sever the tag from the shell.

One major disadvantage of the tagging method is that it is time consuming. One person could clean and tag 50 conchs in about 3 hrs.

Study Areas

Two study areas were used. The Media Luna site is a calcareous sand and algal plain located 5 km south of La Parguera on the insular shelf at 17 m depth. Species of *Dictyota*, *Gracilaria* and *Laurencia* are among the dominant macroalgae. The area was described in greater detail by Ballantine (1977).

The second site, Guayacan, is located inshore in a dense sea grass bed dominated by turtle grass, *Thalassia testudinum*, at 2.5 m depth. Interspersed among the sea grasses are macroalgal clumps, with *Halimeda opuntia* being particularly abundant.

Experimental Design

Prior to release, the individual length and average weight of each conch was measured. The sizes ranged from 20 to 50 mm. One group of conchs, maintained for growth comparisons, was kept in tanks and served as controls. These were fed an abundance of macroalgae for the duration of each experiment.

The basic design of the experiment consisted of releasing conchs around a center point within a 16-m-radius study area. Periodically, typically every 2 weeks, the area was resurveyed by divers. All live conchs within each meter from the center were enumerated and tag numbers, if present, recorded. Dead individuals were collected. Sampling was usually more intensive during the first 2-week period. On one sampling, during the second week, the exact position of each individual was measured by taking its distance from the center and the angle between the center and magnetic

north to the nearest 10 degrees, using a compass.

To date, there have been five release experiments (Table 1). The earlier experiments were preliminary and will not be discussed directly. The major results reported here were obtained from the final three experiments. The small number of conchs released per experiment is compensated by replication between experiments and between species.

Table 1. Schedule of Tagging Experiments.

Experiment	Starting Date	Area	Number Released
1	30 November 1981	Media Luna	49 <u><i>S. gigas</i></u>
2	1 March 1982	Media Luna	60 <u><i>S. gigas</i></u> 54 <u><i>S. costatus</i></u>
3	6 April 1982	Media Luna	56 <u><i>S. gigas</i></u> 83 <u><i>S. costatus</i></u>
4	13 July 1982	Guayacan	51 <u><i>S. costatus</i></u>
5	1 October 1982	Media Luna	97 <u><i>S. gigas</i></u> 50 <u><i>S. costatus</i></u>
		Guayacan	101 <u><i>S. gigas</i></u> 51 <u><i>S. costatus</i></u>

RESULTS

Behavior

Conchs placed offshore began burrowing activity immediately upon release. Very rarely was a conch subsequently seen on the surface. Completely buried conchs could only be detected by the tag protruding from the sediment (Fig. 2). Partially buried conchs were equally cryptic after developing epiphytic growth on the shell.

Randall (1964) reported that a few small conchs were found while diving at night, where none were found during the day. The hypothesis of nocturnal surface activity was explored through a night dive made during one of the experiments. The tagged conchs were easily located. However, no differences in the vertical position or activity of the conchs, both *S. gigas* and *S. costatus*, were noticed. Such nocturnal activity, however, was observed for larger individuals of the West Indian fighting conch, *S. pugilus*.

Behavior differed markedly at Guayacan. In the grass beds no conchs were observed buried in the sediment, which was anoxic just below the surface (Fig. 3). Sea grass provided a more three-dimensional habitat, and conchs were usually found low in the bed, often beneath or, less commonly, on top of clumps of *Halimeda* and other macroalgae.

Dispersion

Position data were used to calculate dispersal coefficients in the manner of Jones (1959; 1966). The mean square diffusion coefficient (a^2) measures the random

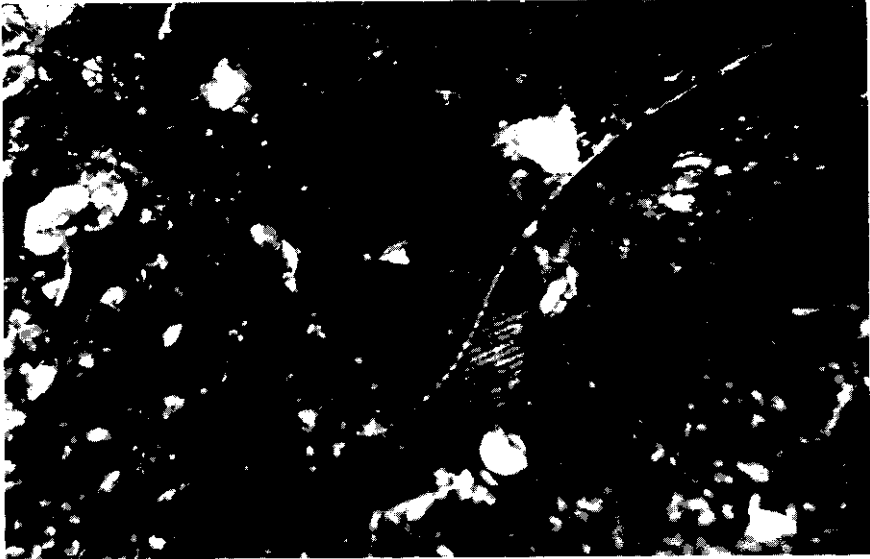


Figure 2. A completely buried *S. gigas* at Media Luna with the tag protruding from the sediment.



Figure 3. A 33 mm *S. gigas* at Guayacan, located at the bottom of the sea grass bed.

movement of individuals. Directed movement, or migration, is measured by the mean direction of dislocation (Ψ) and V , the mean velocity of dislocation in the direction Ψ . The ratio a^2/V indicates the significance of directed movement. A low value of a^2 and a high value of V signifies a strong migrational trend. The resulting coefficients are given in Table 2.

Generally, movement following release was random and slow with the conchs gradually diffusing away from the point of release. During one experiment several individuals showed no movement for a period over 1 week; one individual was observed not to move during a 37-day period. Dispersal within the grass bed was slower than observed offshore. Significant correlations were found between grass conch size (initial length) and distance from the release point indicating that rate of diffusion is proportional to size. For example, in Experiment 5, Media Luna at 14 days, the

relationship obtained by least-squares regression was: Initial Length (mm) = 27.2 + 2.50 Distance (m), $p < 0.05$. The exact nature of this relationship will change as dispersion continues.

The rate of directed movement was typically low. However, there is some consistency in the direction of movement, being toward the southwest. This direction is roughly offshore and perpendicular to the prevailing wind and waves, and hence, bottom surge.

Table 2. Dispersal coefficients for *S. gigas*. Day is the number of days after release when measurements were taken. See text for coefficient definitions. Units for $a^2 = \text{m}^2/\text{day}$; $V = \text{m}/\text{day}$; $\Psi = \text{degrees}$.

Experiment	Area	Day	a^2	Ψ	V	a^2/V
3	Media Luna	8	1.48	230.7°	.064	23.04
5	Media Luna	10	1.19	191.6°	.194	6.12
5	Guayacan	10	.84	222.3°	.129	6.53

Growth

Growth estimates were initially based on the difference in sample mean length between release and recapture. This proved unreliable for two reasons. First, with only few conchs recaptured the estimates were highly variable. Second, because of the relationship between size and rate of dispersal, it can be assumed that a greater proportion of large individuals move outside the sampling area thus reducing their chances of recapture. This results in a low biased estimate for mean length at recovery. Growth estimates were therefore based on size differences for individually marked conchs.

In Experiment 5 conchs grew an average of 0.21 mm/day ($N = 36$) at Media Luna, 0.17 mm/day ($N = 16$) at Guayacan, while controls, kept in a cement tank with preferred foods, grew 0.15 mm/day ($N = 25$). Growth at Media Luna was statistically greater ($p = 0.05$) than for the other two groups, which were not significantly different from each other. Also, growth at Media Luna was significantly more variable, the standard deviations being: $S_{\text{Mtl.}} = 0.074$ mm/day vs $S_{\text{Guay.}} = 0.041$ and $S_{\text{Cont.}} = 0.047$ mm/day, $p < 0.005$. Only one conch from Experiment 3 was identified to the individual: it grew 0.22 mm/day.

Mortality

Losses of tagged conchs can be attributed to mortality, migration outside the study area, and missed observations during sampling. Mortality estimates were based on the number of dead conchs accounted for. This produces a minimum estimate since shells could be carried outside the study area by predators or by hermit crabs after predation. Mortality was estimated by the proportion of dead conchs recovered to total found. This proportion was divided by the time between sampling dates to obtain the mortality rate. This method of calculation is unbiased due to missed observations and migration out of the study area assuming both processes are unselective with respect to mortality.

In Experiment 3, mortality was initially low during the first few days, then quickly elevated to and fluctuated about 4-5%/day for the duration of the experiment (Table

3). A similar pattern was observed for *S. costatus*. This rate of mortality yields a coefficient of instantaneous mortality (z) of over 15 (where $n_t = N_0 e^{-zt}$ with N_0 = number released, N_t = number alive at time = t in years; Ricker, 1975). Eighty percent of the released *S. gigas* were recovered dead. This yields an absolute minimum estimate of $z = 10.6$ assuming all nonrecovered conchs survived. Mortality for milk conchs was similar.

In Experiment 5 a similar pattern was observed (Table 4). At both sites mortality was initially low, then increased. At Media Luna mortality fluctuated about 0.9%/day while at Guayacan it was considerably higher, fluctuating about 2.5%/day. Both of these estimates are markedly less than observed during Experiment 3. In Experiment 1 no accurate estimates of mortality were obtained but it was obvious from the data that mortality, again, was less than in Experiment 3.

In Experiment 4, using *S. costatus*, there was less mortality observed than for either *S. gigas* or *S. Costatus* at Guayacan during Experiment 5. If all nonrecovered

Table 3. Mortality results for Experiment 3: proportion of dead *S. gigas* to total number counted at each sampling, and the percent mortality/day for each period between sampling dates. Sampling day indicates time after release.

Sampling Day	1	3	8	14	26	42	56
Proportion Dead	0	0	.071	.047	.744	.500	.719
% Mortality/Day	0	0	1.43	.775	5.31	3.57	5.10

individuals were assumed dead (which is not likely) the maximum rate of mortality in Experiment 4 would have been 1.46%/day. The minimum estimate was 0.4%/day.

The overall result is that mortality, in the short term, tends to be highly variable between experiments making comparisons difficult. Rates between 1% and 3%/day were most common, corresponding to $z = 3.67$ to 11.11.

By examining returns of dead individuals patterns of mortality could be assessed. Returns were classified as crushed shells, whole shells or tags. The first group consisted both of crushed shells, with often only the top of the spire still attached to the tag, and of spirally cut shells (Randall, 1964: fig. 12, p. 279). Two types of tag returns were found. The dominant type consisted of badly damaged, apparently chewed, tags. Such damage was not evidenced in either crushed or whole shell returns. The other type of tag was not damaged but cleanly broken off.

Consistent patterns in the proportion of each class were observed. Crushed shells were the most abundant, typically forming over 80% of the returns. The proportion of whole shells was 5% at Media Luna and 32.5% at Guayacan for all experiments and species pooled. This difference was statistically significant ($p < .005$).

DISCUSSION

The movement of small juvenile conchs was found to be low and predominantly random. These observations are consistent with those made by Hesse (1979) who found that juveniles in the size range of 10-13 cm had an approximately 1000 m² home range. Small juveniles on sand bottom were rarely unburied. In the sea grass bed they remained primarily at the base of the sea grasses but were never observed buried in the sediment. This differs from Brownell (1977) who found juveniles buried among the roots of marine grasses. These observations indicate that for the period following release, conchs will generally remain within the proximate area. This becomes significant for stocking if it is found that habitat conditions

Table 4. Mortality results for Experiment 4: proportion of dead *S. gigas* to total number counted at each sampling, and the percent mortality/day for each period between sampling dates. Sampling day indicates time after release

Area	Media Luna			
Sampling Day	5	10	14	28
Proportion Dead	.022	.042	.038	.149
% Mortality/Day	.435	.842	.949	1.06

Area	Guayacan			
Proportion Dead	.073	.138	.109	.318
% Mortality/Day	1.46	2.76	2.73	2.27

greatly affect growth and survival, or if habitat modification is employed to reduce predation.

An optimal nursery habitat, if such exists, has yet to be determined for *S. gigas*. Randall (1964) found only a few small juveniles, though many large ones, on a sandy-coral rubble bottom. In contrast, Brownell (1977) found small juveniles in sea grass beds. In the present study results were generally too variable to predict optimum habitat conditions. For example, the clear advantage of the algal plain habitat in terms of growth and mortality exhibited in Experiment 5 was contradicted by the results of Experiments 3 and 4. This indicates the obvious need for further research on *Strombus* early life history.

Although growth in field populations was equal to or greater than controls it was less than the previous maximum rate observed for small juveniles under optimum conditions, i.e. 0.4 mm/day (Ballantine and Appeldoorn, 1983). Average growth rates for small conchs, predicted from von Bertalanffy growth functions, range approximately from 0.24 — 0.32 mm/day (Berg, 1976; Alcolado, 1976). Alcolado (1976) found growth to be highly seasonal, with maximum growth occurring during summer months. Growth observed here was much slower than predicted, but given seasonal variability verification of the difference will require further study.

Crushed shells were most abundant among recaptures of dead individuals. Randall (1964) listed 22 species observed either feeding on *S. gigas* or with remains in their stomachs. Most were fish, but only a few of these were thought to be actual predators. Retention of shell fragments within the study area and the patterns of breakage suggest crustaceans as the dominant predator group. Spiny lobsters are known to prey on conchs, producing broken shell patterns similar to those recovered during the experiments (Randall, 1964; personal observation). When placed in a natural bottom tank containing buried conchs, lobsters elicited a vigorous escape response. Robertson (1961) reported a similar response by conchs to tulip snails, *Fasciolaria tulipa*. Other crustaceans, such as box crabs, *Calappa*, are probably predators as well, though no such relationship has been observed. Randall (1964) observed the large hermit crab, *Petrochirus diogenes* feeding on *S. gigas* by insertion of the chelae into the aperture of the conch. Kept in an aquarium, however, *P. diogenes* did not attack small conchs over a 2-week period (personal observation).

The abundance of empty shells recovered at Guayacan may indicate predation by

tulip snails. Only one *Fasciolaria* was observed within the study area, but they are known to be common in sea grass beds and efficient predators on conchs (Randall, 1964; Jorry, 1982). Empty shells collected typically contained hermit crabs but there was no evidence they were responsible for the predation.

Of paramount interest is the nature of the natural mortality function throughout the life span of *S. gigas*. Berg's (1976) analysis of Randall's (1964) tagging data resulted in an average mortality rate of 0.82%/day, or $z = 3.03$ between the ages of 1 and 2.25 years. Alcolado (1976) reported z values averaging 1.4 for juveniles between 2 and 3 years of age. These values are thought to represent natural mortality only. In the present study significantly higher mortalities were observed. The indications are that *S. gigas* mortality decreases substantially with age/size.

To further illustrate this point, Berg's (1976) data (fig. 5, p. 196) were reanalyzed to obtain mortality estimates for each interval between his 6 points. These data were pooled with that of Alcolado (1976) and from the present study, and regressed against age at the midpoint of each interval. For the present study, an average z between 3.67 and 11.11 equaling 7.36 was used, with an age of 0.22 years based on Randall's (1964) growth data. The resulting regression: $z = 7.61 - 2.59 \text{ Age (years)}$, $r^2 = 0.92$ has significant implications. Given the variability inherent in the data, the true relationship may not be linear as indicated here. However, the purpose here is not to describe the exact form of the mortality function, but only to demonstrate its dynamic nature.

Given the above mortality, good survival of adult conchs might be expected. Indeed, Randall (1964) reported only the loggerhead turtle, *Caretta caretta*, rare in Puerto Rico, as a major predator of large conchs. However, estimates of early mortality remain high, significantly higher than, for example, in commercially important bivalve species. If analogy can be made from fish mortality patterns, a higher mortality rate in tropical environments would be expected (Pauly, 1980) so the above estimates should not be discounted without specific contradicting evidence.

Berg (1976) stated that conchs reach commercial size in 2.5 years. At the above rate of mortality, the survival of 1 million half-year old conchs (roughly 60 mm) would be on the order of 0.1% by age 2.5. The seeding of small conchs, unprotected, into the natural environment does not appear to be a practical way to support such a fishery. This conclusion is tentative, being based on preliminary data, and does not take into account specific measures that could be developed to enhance juvenile survival.

It is felt that strong management measures are required in the restoration of conch stocks and fisheries to their former levels. A policy which permits the harvesting of a significant proportion of the population before maturity and reproduction will by design result in the depletion of the stock and collapse of the fishery. Conservation measures should ultimately be based on a sound understanding of the biology of the exploited species and its fishery. However, management should not wait for the accumulation of such knowledge before acting, when the need for conservation becomes readily apparent.

Given strong management measures, it may be possible to use seeding within a particular area to build up the breeding population. Once a population has been sufficiently restored it should, with proper management, remain self-sufficient. With an estimated reproductive life of less than three years (Berg, 1976) for *S. gigas*, consistent recruitment is required to sustain high fishing pressure. Stocking may then also be useful in areas where recruitment fails periodically, to stabilize the future spawning capacity of the stock.

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