Assessment of the Queen Conch (Strombus gigas) Population and Predation Studies of Hatchery Reared Juveniles in Salt River Canyon, St. Croix, U.S. Virgin Islands

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ABSTRACT

During 1983 and 1984 studies on queen conch have been conducted at depths in the Salt River Submarine Canyon, St. Croix, U.S. Virgin Islands. This canyon supports a large population of conch of which 242 have been tagged, weighed and measured. Because of the continuous saturation diving missions conducted by NOAA's Undersea Research Program in the Hydrolab, observations on this population have been frequent. With the relaxation of fishing pressure in the canyon since 1978 when Hydrolab operations began, queen conch have been able to live relatively undisturbed by man in a natural environment. This unique situation provided a natural area closure experiment.

Patterns of seasonal migration and behavior have become apparent from these continuous observations. During the winter conch migrate down the slope and have been found at depths as great as 150 ft. In March the conch become very active on the grass and algal flats between 50 and 70 ft. Mating and egg laying have been observed from March well into November. Deep water populations such as these could represent most of the reproductive capability of the conch in this area.

The mean length and weight of the Salt River Canyon queen conch population is much larger than any shallow water population previously studied. The age of conch in the canyon is also well above the maximum age previously suggested with the largest conch captured estimated to be between 8.4 and 26 years of age.

During the December 1984 Hydrolab mission, the introduction of juvenile hatchery-reared conch was studied in the canyon. During the experimental procedures all unprotected introduced juveniles not in the vicinity of the habitat were attacked and killed by the hermit crab *Dardanus venosus*. Unprotected juvenile conch released in the vicinity of the habitat, where there were considerable diver and operational activities, were not attacked by predators even when known predators were introduced into cages with juvenile conch.

Releases of juvenile conch are not practical at this time until further techniques are devised to increase their survival; management of natural populations is therefore proposed. We recommend that large, reproductively active populations existing in deeper water be given protection. Laws preventing collection of conch with SCUBA might be a very effective management tool to insure the production of larvae for populating shallow as well as deep areas. Area closures in selected deep water sites and the introduction of adults to enhance egg production to these areas can also be considered as a management technique.

INTRODUCTION

As queen conch (*Strombus gigas*) populations decline throughout the Caribbean, hatchery construction and operations are on the rise serving to increase knowledge of mariculture as a means to combat the increasing decline of this valuable fishery resource. However, our knowledge of introduction techniques to insure survival of hatchery-reared juveniles is essentially non-existent. In fact, predation on juveniles has been found to be so high that caged growout may be the only solution (Appeldoorn and Ballantine, 1983; Iversen et al., 1986). In addition, management of natural populations is either non-existent or ineffective in increasing or stabilizing existing populations. Research in juvenile seeding and growout together with effective management techniques must be a primary focus in any plan to enhance queen conch populations.

Since January, 1984 studies on queen conch have been conducted at Salt River Submarine Canyon, St. Croix, U.S. Virgin Islands as part of the National Undersea Research Program at the West Indies Laboratory. In this small submarine canyon ranging in depth between 50 and 100 ft there exists a large population of queen conch. We studied this population in this semi-enclosed and protected habitat in order to compare population characteristics of the conch living below 65 ft with several comprehensive studies on this animal in shallower, more heavily exploited areas. The research effort of the past 2 years revealed many important differences existing in this deep water population which led to proposed management recommendations.

The feasibility of introducing hatchery-reared juveniles into deeper waters was also studied. We indicate the possibility that lower predator diversity and density in deep water habitats could increase survival rates of conch, especially away from the reef on the sandy bottom of mid-canyon. Juvenile predator avoidance behavior was also examined as observations could be made *in situ* on a 24-hour basis for 7 days.

METHODS

Study Site

The study site is located in Salt River Submarine Canyon on the north shore of St. Croix (Fig. 1). The canyon begins at the

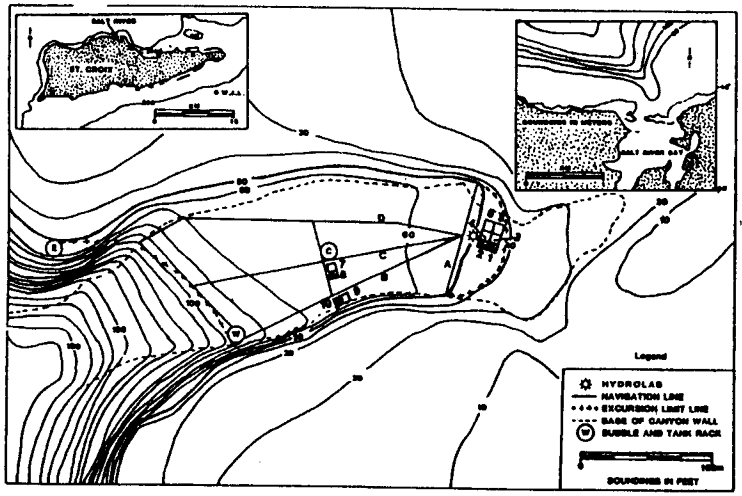

Figure 1. Topographical map with cage locations and identification numbers shown. Upper left: Location of Salt River Submarine Canyon on St. Croix. Upper right: Location of Salt River Submarine Canyon and associated Salt River Bay.

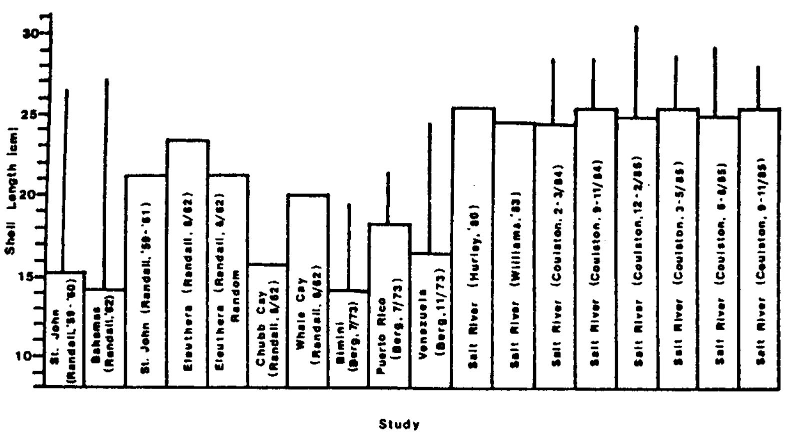

Figure 2. Mean and upper range of conch shell length from Salt River Submarine Canyon population (based on samples of Hurley, et al., 1980; Williams, 1983; Coulston, 1984 and 1985) compared with other studies (Randall, 1964 and Berg, 1976).

barrier reef outside of the Salt River estuary, where the underwater habitat Hydrolab sat in 51 ft of water, and extends downward to a depth of 12,000 ft. The canyon is approximately 100 m wide and is bounded by a steep vertical wall to the west and a gently sloping wall on the east (Josselyn et al., 1983). The floor of the canyon is composed of medium sand to silt. The deep water seagrass, Halophila decipiens, is abundant but patchily distributed throughout the study area. Halimeda spp. and Caulerpa spp. are also present within the canyon between 55 ft and down to at least 150 ft. Drift plant material also represents an available food resource in the canyon; Thalassia testudinum, Syringodium filiforme, Halophila decipiens and algae from the genera Dictyota, Dictyopterus and Dilophus compose most of this drift material (Josselyn et al., 1983). Fish herbivores are numerous in the canyon (Robblee and McIvor, 1983), and herbivorous invertebrates are also present, such as the sea urchin Tripneustes ventricosus and the conchs, Strombus gigas, S. costatus, S. gallus and S. pugilis (Coulston, 1984). Predators of the queen conch found in the study site include the southern stingray (Dasyatis americana), spotted eagle ray (Aetobatis narinari), several species of hermit crabs (Petrochirus diogenes, Dardanus venosus), apple murex (Murex pomum) and octopus (Octopus spp.) (Coulston, 1984).

Tagging

In February, 1984 fifty eight queen conch were tagged using plastic self-locking tie wraps secured around the spire with a numbered Dymo label attached. Most of the plastic tie wraps remained on the animals but the Dymo labels did not, consequently in March the method of tagging was changed. Holes were drilled through the shell, Floy spaghetti tags were inserted through the holes and secured using Pettit underwater epoxy patching compound applied on the outside. This method of tagging was very successful; tags have lasted at least 20 months.

Population Sampling

The population was sampled at periodic intervals from February 1984 and monthly from October 1984. During saturation mission 84-14 (November 29 to December 6, 1984) the canyon floor from 50 to 100 ft depth was intensely searched for queen conch. This area is approximately 28,770 m^2; averaging 230 m in length and 100 m in width from the east to the west wall of the canyon. Recaptured tagged conch were recorded and untagged ones were tagged and measured.

During routine sampling periods divers read tags, recorded depth and activity of the conch and brought untagged conch to the surface for tagging, weighing and measuring. The conch were then returned to their area of capture. During each three month period the conch were marked with different colored flagging tape. Conch recaptured from a previous three month period, as determined by the color of the flagging tape, were also brought to the surface to be re-weighed and re-measured.

Estimates of population size were made using the Peterson method where population size, N, is estimated by the equation: $N/M = n/R$, where M is the number of marked animals, n is the second sampling of individuals of R recaptured animals (Bower and Zar, 1977).

Monthly estimates of population size were made based on animals that had been previously tagged with Floy tags. We assumed that at recapture all marked conch were equally available for recapture and that all tags had remained secured to individuals unless otherwise found.

During routine sampling, egg laying and mating of tagged conch were recorded, sex was also recorded when it could be determined. For all captures and recaptures the age, whether the conch was a juvenile, young adult (where the lip was just beginning to flare), or adult, was recorded (Table 2).

Age classes of juvenile conch were determined from frequency distributions of weight (Fig. 3) and length. Second and third year classes were distinguished from conch older than 4 years of age (Table 3).

Age Determination of Conch

Continued increases in conch weight have allowed us to estimate their age. By calculation of the mean weight gain per month of the conch the age of a conch can be estimated from its weight. From our frequency distribution of weights a 2 year class has been defined, and its mean (SD) weight calculated, thus additional increments of weight can be evaluated in terms of months.

Introduction of Hatchery-Reared Juveniles: Predation Study

During the seven day saturation mission in December 1984, hatchery-reared juveniles obtained from Tradewinds Industries, Inc., Turks and Caicos Islands, were used to examine predation in the canyon. Covered and uncovered cages constructed of 1/2" mesh hardware cloth were placed close to the reef and mid-canyon, in anticipation of finding different predators at each site (Table 1). In order to verify the assumed diurnal migration into the sediments by juveniles, cages were placed in front of the habitat's viewing port for continuous 24 hour observation. The additional uncovered cages were used for predator introduction. Table 1 summarizes the experimental design and the number of conch placed in covered and uncovered cages.

On the last day of the December 1984 mission 65 juvenile conch were tagged and released just outside of the habitat at 50 ft. Four individuals in the covered cage at the reef-edge and the 4 individuals in the covered cage at mid-canyon were also left on the bottom for future observation.

Table 1. Summary of hatchery reared juvenile conch predation study.

LOCATION/CAGE#	NUMBER OF CONCH	DESCRIPTION
COVERED CAGES		
Habitat (#1)	5	5 of 5 unharmed after 6 days, all remained on the surface, 2 partially buried on day 6
Habitat (#2)	10	8 of 10 unharmed after 6 days, 1 unaccounted for, 1 occupied by hermit crab
Mid-Canyon (#8)	4	4 of 4 unharmed after 5 days, all remained on the surface, 1 partially buried day 5
Reef-edge (#10)	4	4 of 4 unharmed after 5 days, all remained on the surface, 1 partially buried on day 3
UNCOVERED CAGES		
Habitat (#3)	5	5 of 5 unharmed after 6 days, all remained on surface
Habitat (#4)	5	5 of 5 unharmed after 6 days, all remained on surface
Habitat (#5)	10	10 of 10 unharmed after 6 days, all remained on surface
Habitat (#6)	5	5 of 5 unharmed after 6 days, all remained on surface
Mid-Canyon (#7)	4	day 1: 1 being attached by hermit crab, 2 already outside with hermit crabs inside, 1 buried (on day 2 occupied by hermit crab)
Reef-edge (#9)	4	day 1: 1 occupied by hermit crab, 2 unaccounted for and 1 unharmed day 2: 2nd occupied by herdit crab, later the 2 unaccount for were found occupied by hermit crabs

NOTE: All hermit crabs attacking juvenile conch were *Dardanus venosus*.

Table 2. Summary of queen conch captured, marked and recaptured during specified study months. Also included is a breakdown of adults, young adults and juveniles, sex, mortalities, tags found, egg laying and mating pairs are indicated where known

Study Month	Number Marked	A	YA	J	Never	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	SEX ?	SEX M	SEX F	DEAD	TAG FOUND	EGG LAYING	MATING PAIRS
2/3 FEB MAR	101	98	2	1	58(1J)	-	-	-	-	-	-	-	-	2	1	1	11	-	-	1	7	1	8	2	96	2	3	6	4	3	1
7 JUL	16	15		1	1(1J)	-	-	-	-	1	-	-	1	-	-	-	5	1	5	2					14	1	1			1	1
10 OCT	21	10	3	8	6(5J)	-	2	-	-	5	-	-	5	-	-	3	-								19		2			3	
11 NOV	2	1		1	0	-	-	-	-	-	-	-	-	-	1	-									2				1(J)	1	
12 DEC	26	17		9	10(8J)	-	-	1	-	-	-	7	1	4	3										24		2	1		1	1
14 FEB	13	11		2	2	2	-	1	1	1	2	4	-												12		1				
15 MAR	14	13		1	3(1J)	1	-	1	4	2	5	-													14						1
17 MAY	3	3			1	-	1	-	1	-															2		1				1
18 JUN	11	8	2	1	4	-	2	4	1																8	1	2			1	1
19 JUL	18	17		1	10	-	6	2																	17	1					3
20 AUG	4	4			4	-	-																		4						2
21 SEP	10	10			10	-																			10		1			1	1
22 OCT	3	2		1																					3						1
TOTALS	242	209	7	26	99																					5	11	7	5	10	13

242 -(7 dead) -(5 tags found) = 230 presently marked and assumed alive in the canyon.

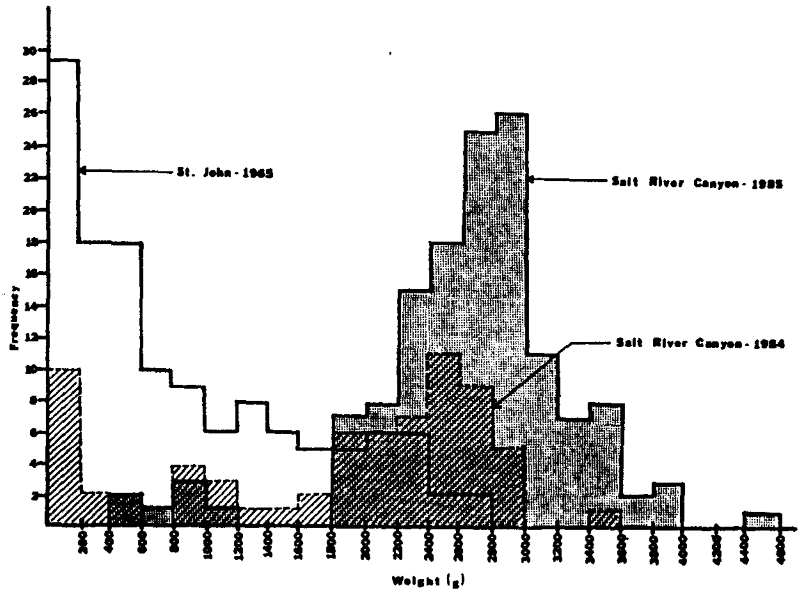

Figure 3. Frequency distribution of queen conch weights from the Salt River Submarine Canyon population sampled in 1984 and 1985 compared to the St. John population sampled by Randall (1964).

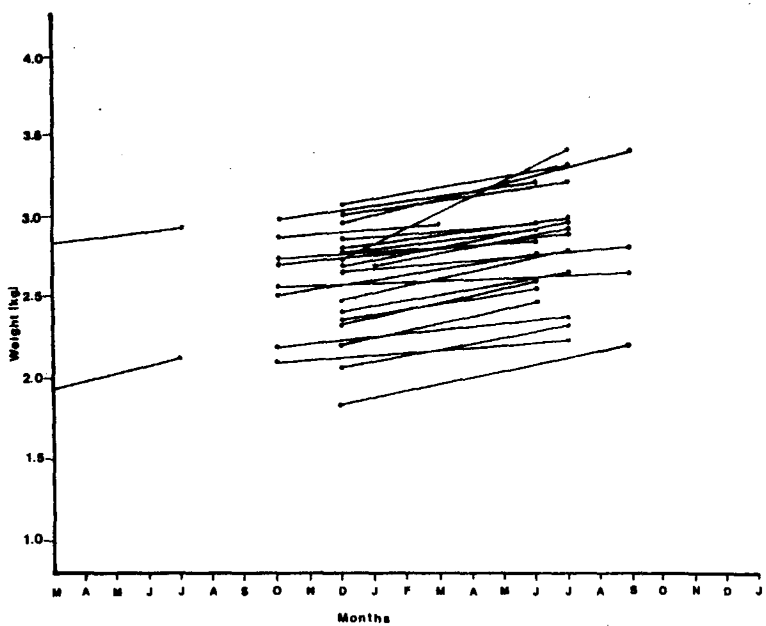

Figure 4. Change in weight of queen conch over indicated periods of time.

RESULTS

Capture/Recapture Study

A summary of tagged queen conch capture-recapture data appears in Table 2. Calculations made of population size in June, July, August and September, 1985 are respectively 195, 203, 231 and 185 using the Petersen method. In all these calculations the number of marked individuals was based on those with permanently secured Floy tags. We know that 242 were tagged and assume, considering known mortalities, that 230 are alive and in the canyon.

Juveniles were not found frequently during routine sampling. The greatest number were found during the December saturation mission, between 80 and 100 ft, buried in the sand. As noted (Table 2), once captured the juveniles are rarely seen again. It will take long periods of searching using saturation diving to determine if the juveniles spend most of their time buried or are simply the victims of predation.

Patterns of seasonal migration have become apparent from these continued tagging and recapture studies. The overwintering period is estimated to begin sometime during the month of November when the water temperature (measured at 50 ft) drops from about 28.5°C to 26.0°C (J. Ogden, pers. comm.). This overwintering was observed during the December 1984 saturation mission when most of the conch were found at depths greater than 80 ft buried in the sand. It is uncertain to what depths conch migrate. They were sighted at 150 ft during the October 1984 mission and 86% of the conch captured during the August 1980 mission were found at depths between 95 and 100 ft. About March they begin to migrate to shallower depths and a considerable number of them are found on the seagrass and algal flats around 65 ft. Sightings by aquanauts indicate that conch are abundant and reproductively active throughout the canyon from March to November. Until additional saturation diving missions are possible, allowing time at deeper depths to study the conch, we cannot be certain of conch behavior below 80 ft.

Salt River Submarine Canyon Population Structure

The mean length and weight of the Salt River Canyon queen conch population is much larger than any shallow water population previously studied (Fig. 2). In adult conch, weight is a better indicator of age as conch decrease in length with age due to erosion (Randall, 1964). We have found no correlation between weight and length in adult animals. Table 3 summarizes weight and length of adults within each three month period and mean weights and length divided into 1, 2 and 3 classes as determined by peaks in the frequency distribution (Fig. 3). In the juvenile population there is a correlation ($r = .91$, $P < .001$) between length and weight indicating that either measurement can be used efficiently to measure conch age. The weight and length of hatchery-reared juveniles is also summarized in Table 3.

Most conch are sexually active from March through November.

Table 3. Weight and length of adult queen conch captured in Salt River Canyon grouped by 3 month periods. Juveniles, both naturally occurring and hatchery reared, are listed separately.

Months	Weight(g) $\bar{X}$	SD	n	Length(cm) $\bar{X}$	SD	n
Feb/Mar 84	no data			23.8	+1.3	63
				(20.0–28.0)		
Sep/Oct/Nov 84	2626.1	±361.2	17	24.9	±1.9	18
	(2004.8–3110.0)			(22.1–27.9)		
Dec/Jan/Feb 84/85	2521.7	±463.8	39	24.5	±1.6	39
	(1215.7–3050.0)			(21.5–30.0)		
Mar/Apr/May 85	2708.1	±384.7	24	24.7	±1.5	24
	(1910.6–3500.0)			(2[illegible].9–28.2)		
Jun/Jul/Aug 85	2787.2	±494.1	75	24.4	±1.6	75
	(1884.0–3900.0)			(21.2–28.5)		
Sep/Oct/Nov 85	2824.8	±575.5	18	24.8	±1.4	18
	(2142.1–4500.00			(22.5–27.4)		
Juveniles (Salt River Canyon)	999.9	±173.2	14	22.4	±1.9	18
	(765.8–1440.0) 3rd year class			(18.0–25.7)		
	222.3	±164.7	15	12.9	±2.2	14
	(63.6–561.3) 2nd year class			(10.3–17.6)		
	3.3 1st year class		1	6.9		1
Juveniles (hatchery reared)	8.8	±2.9	22	4.8	±.8	29
	(4.4–14.2)			(4.0–6.0)		

Table 4. Summary of changes in weight and length in queen conch over varying number of months, original weight at first capture and average weight change.

Number of Months	Months (Capt-Recapt)	Weight (gm)	Length (cm)	Original Weight	Average Weight gain per month
4	MAR–JUL	+ 195.1	- 0.1	1910.6	48.7
4	MAR–JUL	+ 76.8	+ 0.5	2814.0	19.2
5	OCT–MAR	+ 5.0	- 0.6	2336.3	1.0
5	OCT–MAR	+ 100.7		2840.0	20.1
5	FEB–JUL	+ 224.7	+ 1.2	2680.0	44.9
6	DEC–JUN	+ 101.0	0.0	2839.0	16.8
6	DEC–JUN	+ 268.1	- 3.5	2171.9	44.6
6	DEC–JUN	+ 233.9	+ 0.2	2672.1	38.9
6	DEC–JUN	+ 269.5	+ 0.2	2310.0	44.9
6	DEC–JUN	+ 189.9	+ 0.3	2326.3	31.6
7	DEC–JUL	+ 250.0	- 0.1	3050.0	35.7
7	DEC–JUL	+ 213.6	- 1.1	2760.5	30.5
7	DEC–JUL	+ 250.2	- 0.1	2385.0	35.7
7	DEC–JUL	+ 212.0	- 4.5	2988.0	30.2
7	DEC–JUL	+ 692.3	+ 0.1	2707.7	98.9
7	DEC–JUL	+ 269.6	+ 0.1	2034.4	38.5
7	DEC–JUL	+ 223.5	- 0.4	2461.2	31.9
7	DEC–JUL	+ 174.8	- 3.2	2770.0	24.9
8	OCT–JUN	+ 260.0	+ 0.2	2490.0	32.5
8	OCT–JUN	+ 113.9	- 2.9	2778.4	14.2
8	OCT–JUN	+ 706.4	+ 1.1	1138.4	88.3
9	OCT–JUN	+ 138.1	- 0.8	2683.0	17.2
9	OCT–JUN	+ 238.8	+ 0.1	2961.2	29.8
9	OCT–JUL	+ 116.0	0.0	2084.0	12.8
9	OCT–JUL	+ 200.0	- 0.1	2160.0	22.2
9	OCT–JUL	+ 177.0	- 1.1	2698.0	19.6
9	DEC–SEP	+ 181.9	- 0.2	2627.6	20.2
9	DEC–SEP	+ 447.3	+ 0.2	2952.0	49.7
9	NOV–SEP	+ 390.2	0.0	1805.1	43.3
11	OCT–SEP	+ 99.1	0.0	2535.9	9.0

Average Weight gain per month is 33.2 ± 20.6 g

The peak in reproductive activity seems to be June through August; aquanauts have observed many mating pairs and a considerable number of egg masses throughout the canyon during this period. One mating pair was observed and one female was seen laying eggs during the December mission. One female was observed laying eggs both in June and again in September. There is no doubt from the number of matings and egg masses observed that this population is a potentially important contributor of offspring.

Age Determinations of Queen Conch

Continued increases in conch weight over time have allowed us to estimate their age. The average weight gain per month was calculated to be 33.2   20.6 gm (n=30). In all cases conch gained weight (Table 4). The amount of adult weight gain is not a function of age as there is no correlation between amount of weight gained and weight at first capture. It is apparent that regardless of age, adult conch gain weight at a similar rate (Fig. 4).

Consistent weight gain allows us to make estimates of the age of the conch in the canyon. At approximately 3 years of age, conch reach sexual maturity and begin to lay down a thin flared-lip (Berg, 1976). Using this criteria to indicate 3 years of age, the mean weight estimate of 3 year old conch in Salt River canyon is 999.9   172.2 g. The heaviest conch captured weighed 4.5 kg. Therefore, using weight gain/month and the assumption that a conch in the canyon weighs about 1 kg at 3 years of age, we estimated that the largest conch is 12 years old (using means) with a probable range of 8.4 - 26 years (considering variation).

Juvenile Predation Study

Juvenile queen conch left in the open mid-canyon and reef-edge cages were all killed by the hermit crab, Dardanus venosus, within the first two days (Table 1). We observed an attack in which the crab pulled the conch's foot for at least three hours until the conch was pulled free from the shell. In other cases where the removal of the conch from shells was not observed, hermit crabs were found inside all the shells. In contrast, only one conch in the cages near the habitat was killed during the 6 days of observations even with repeated introductions of D. venosus and Petrochirus diogenes into the cages and the observation that an octopus moved freely throughout most of the open cages over a period of several hours. Introduced predators showed no recognition of the conch nor did the conch exhibit any predator avoidance behavior. This could be partially attributed to unnatural substances in the water around the habitat that could interfere with chemoreception (e.g., waste water containing detergents). However, it is possible that hatchery-reared conch may exhibit modified behavior (Jory et al., 1985). No diurnal migration into sand was observed in this study, as believed to occur in natural populations of juveniles.

After a few days, several of the conch were found partially buried, but no pattern of burying and surfacing was ever observed.

Only 10 juveniles of the 65 originally released have been found. Three of these were recaptured three months later; one was found at 115 ft buried in the sand, approximately 250 m down the canyon from the release site. Three tags have been found, 2 shells found crushed and two shells were occupied by D. venosus.

Conch left in covered cages at mid-canyon and near the reef were alive and buried 3 months later. However, within a week after this observation, all 4 conch in the reef cage were occupied by D. venosus, which entered the incompletely closed cage. The other 4 caged conch were released at that time. They had grown noticeably larger and had a distinct change in the new shell color and pattern.

DISCUSSION

With the decrease in fishing in Salt River Submarine Canyon since 1978, when Hydrolab operations began, queen conch have been able to live relatively undisturbed by man in a natural environment. This unique situation provided a natural area closure experiment. Because the large conch are not being selectively removed by fishermen we have found a much older group of individuals than found by previous investigators. The age of conch in the canyon is well above the maximum ages of 5.1/2 to 6 years previously suggested by Berg (1976) and Hesse (1979) with the age of the largest conch we found in Salt River canyon estimated between 8.4 and 26 years. Continued monthly sampling will allow more accurate age estimation.

The canyon is well populated with reproductively active queen conch almost continually producing egg masses year round. These egg masses are noticably larger than those found in shallower waters, and must play a significant role in providing juveniles.

Juvenile conch releases are not practical until further techniques are devised to increase their survival; therefore, management of natural populations is our immediate concern. We recommend that large, reproductively active populations existing in deeper water be given protection. Laws preventing collection of conch with SCUBA might be a very effective management tool to insure the production of larvae for populating shallow as well as deep areas. Area closures in selected deep water sites and the introduction of adults to enhance egg production to these areas, if the carrying capacity allows, can also be considered as management techniques. The continued study of the Salt River canyon population and the identification of similar densely populated areas, and potential conch stocking areas, is planned with the hope of offering a more complete management plan in the future.

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Practical Considerations in the Assessment of Queen Conch Fisheries and Population Dynamics

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ABSTRACT

Proper management requires reliable information biology, exploitation and stock status of exploited s With queen conchs, data collection and analysis ar complicated by the particular biological and life-h characteristics of the species (e.g., cessation of g length at maturation, partial recruitment, variati mortality, growth and recruitment) and the nature fishery. The problems of sampling and assessment are r with emphasis on the estimation of growth and mortality. attention is given to the use of length-frequency tec Specific examples are included based on original resea literature reports.

While problems do occur, useful information can be obt appropriate precautions are taken. It is strongly rec that, if possible, results be corroborated by add sampling and/or by employing a variety of techniq instances where decisions must be made with inc assessments, it is imperative to consider the variab results and possible consequences of errors when dev management strategies.

INTRODUCTION

Management policies should be designed to achieve socio-economic benefits through the intelligent utiliz fisheries resources. Regardless of management goals, decision-making requires basic, reliable informat fisheries, information on the biology and exploitation o species is prerequisite to the management process. Of pa importance are stock size and rate of production. The l dependent upon the basic biological processes of growth, mortality, reproduction and recruitment, and upon morta to fishing activities.

Literature reports have demonstrated or advoc application of assessment methodologies to populations conch, *Strombus gigas*, with most recent attention being length-frequency analysis, e.g., Wood and Olsen, 1983; 1985. Much can be gained from the analysis of length-f data (see Munro, 1983), as well as data from other However, as with any analysis, data must meet the ass of, or otherwise fit, the assessment techniques use conchs have unique life-history characteristics that co