EXPERIMENTAL ANALYSIS OF HABITAT QUALITY FOR JUVENILE QUEEN CONCH IN SEAGRASS MEADOWS

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ABSTRACT

Field experiments were conducted in the southern Exuma Cays, Bahamas, using mortality and growth rate as indicators of habitat quality for juvenile queen conch <u>Strombus gigas</u>. One year old conch (82-105 mm shell length) were transplanted to 2 locations within resident juvenile conch populations that had different seagrass biomass. One site had low biomass (8-15 g dry wt/m²) and the other had moderate biomass (40-70 g dry wt/m²). Transplants were made to 6 other sites without resident conch populations: 2 sites similar to the moderate biomass site, 2 sites similar to the low biomass site, and 2 sites to test extreme conditions; 1 with heavy seagrass biomass (180 g dry wt/m²) and 1 on bare sand.

Mortality was low at the stations with natural conch populations and/or moderate seagrass biomass. Mortality was high at all of the other sites and increased with time at the sand site and at 1 of the low biomass sites.

Growth rate was high and remained stable at the stations with natural conch populations and at 1 of the sites (C2) with no resident conch population. High growth and survivorship at station C2 suggests that conch populations may be recruitment limited in certain cases. Rapidly declining growth rates were found at all other sites despite depth, sediment, and macrophyte characterisitics similar to sites with resident conch populations. These results show that other important environmental variables were unidentified. Data on standing crops of macrodetritus at the beginning and end of the experiment suggested possible food limitation at some wites.

INTRODUCTION

Seagrass meadows are important nursery habitats for many fish and invertebrates from high to low latitudes (Thayer et al. 1975, Kikuchi & Peres 1977, Weinstein & Heck 1979, Stoner 1983, Pollard, 1984, Robblee & Zieman 1984, Sogard et al. 1987). The queen conch (Strombus gigas L.) is one of the large gastropod molluscs which uses the seagrass habitat as a nursery (Randall 1964). Its food value and large size (to \rightarrow 250 mm shell length) make the conch an important commercial species throughout the Caribbean region (Brownell & Stevely 1981). Hatchery data indicate that pelagic larvae of the queen conch spend 18 to 40 days in the water column (Brownell 1977, Davis et al. 1987, Mianmanus 1988). The larvae then settle and metamorphose in the benthos and live for the first several months in places and in ways mostly unknown at this time. Juveniles between 35 and 40 mm shell length are usually the first sizes observed on sandy shoals and in shallow seagrass meadows, although smaller individuals have been found (Stoner & Sandt, unpubl. data). Primary foods for juvenile stages are seagrass detritus and algae (Stoner 1989a). In seagrass beds of the Bahamas, Turks and Caicos, Virgin Islands, Cuba, and Venezuela juvenile queen conch densities of 1 to 2 animals/m² are common (Alcolado 1976, Hesse 1979, Weil & Laughlin 1984, Iversen et al. 1987, Stoner 1989a). With age, the juveniles move to deeper water (Weil & Laughlin 1984), and sexual maturity occurs at approximately 3.5 to 4.0 years (Randall 1964).

Large seagrass habitats (hundreds of hectares) are found

near Lee Stocking Island, in the Exuma Cays, Bahamas. Much of this habitat appears to be appropriate for juvenile queen conch (depth, sediments, macrophytes); however, the conch are associated with certain sectors of this habitat. Five discrete juvenile populations have been observed in particular localities year after year (Wicklund et al. 1988; Stoner, unpubl. data). Recent observations of mass migration in 1 and 2 year old queen conch away, from two of the population centers has resulted in the hypothesis that large-scale distributional patterns in queen conch are a result of larval recruitment to specific habitats and subsequent dispersal of the benthic juveniles away from the areas of high recruitment (Stoner et al. 1988, Stoner 1989b).

Reported here are the results of experimental transplants of 1 year old queen conch to 8 locations using survivorship and growth as indicators of habitat quality. If survivorship and growth of transplants in areas without resident conch are high or similar to values found in areas with resident populations, then distribution may be a function of differential recruitment. If, on the other hand, survivorship and/or growth are low, lack of juvenile conch in the area may be a function of low recruitment or poor habitat quality (i.e., inadequate foods, high predation rate, etc.) Four habitat types were tested to determine characteristics that are optimal for juvenile queen conch populations.

METHODS AND MATERIALS

Site Description

Experiments with juvenile queen conch were made at 8 sites in the southern Exuma Cays, Bahamas, near Lee Stocking Island (Fig. 1) during the summer of 1988. These sites included 2 which

have natural populations of queen conch juveniles, Children's Bay Cay site 1 (C1) and North Bock Cay site 1 (N1). N1 had low (L) turtlegrass (<u>Thalassia testudinum</u>)biomass, and C1 had moderate (M) turtlegrass biomass (Fig. 2). Two sites were chosen with macrophyte, sediment, and depth characteristics similar to C1, but with no resident conch populations. One was in the same seagrass bed as C1 but 300 m to the southeast (Children's Bay Cay site 2, C2), and the other was west of Lee Stocking Island (L1). An additional 2 sites were chosen to be similar to N1; one site was north of Lee Stocking Island (L3), and the second near Windsock Cay (W1).

To examine the effects of seagrass biomass in extreme cases, 2 additional sites were chosen. A sand bank site was selected where there was no macrophyte cover, but a regular transience of juvenile conch (Children's Bay Cay site 3, C3). One additional site was chosen for high (H) seagrass and detrital biomass, 300 m northwest of L1 (Lee Stocking Island site 2, L2).

Two topless cages were constructed at the 8 experimental sites with 2.0 cm black plastic mesh wired to reinforcement bar driven into the sediment. The cages were 30 cm high, 5 m in diameter, and pushed into the sediment (approximately 2.0 cm) to prevent losses of animals. Locations of the cages were chosen to provide uniformity in macrophyte cover within site, and between the sites selected for similar macrophyte characteristics (C1, C2, L1 and N1, L3, W1).

Previous experiments with the same cage design at the Children's Bay Cay site 1 showed that the cages did not effect sediment grain-size, sediment chlorophyll, or accumulation of detritus. Most importantly, enclosed animals had growth rates

equivalent to individuals tagged and released in the field surrounding the enclosures (Stoner 1989a).

Animals used in this experiment were 1-year old <u>Strombus</u> <u>gigas</u> collected from the sand bank near Children's Bay Cay. At the beginning of the experiment, all of the conch were between 82 and 105 mm total shell length. After measuring habitat characteristics (see below) and clearing all noticable macroinvertebrates from the 16 enclosures, 24 individually tagged and measured conch were placed in each cage at a density of 1.2 conch/m², equivalent to mean summer population density at the Children's Bay and North Bock Cay sites. Replacements for animals lost or killed were of a size similar to the mean conch size in a particular treatment. Marking was made with vinyl spaghetti tags (Floy Tag & Manufacturing, Inc.) tied around the spire of the shells.

All transplants were made by 26 April 1988, and measurements of total shell length were taken with large calipers at approximately 35, 75, and 120 days. The growth period varied by a few days in individual treatments; therefore, growth rate was determined on the basis of mm shell growth per day. Each enclosure was examined at 2 week intervals to determine mortality rates over time, to replace dead conch, and to remove predators. One of the cages at C3 was destroyed by wave action in June, 1988, and all of the enclosed animals were lost. This cage was rebuilt and new animals were placed in the enclosure on June 23.

At the end of the experiment, soft tissue weight of individual conch was determined by carefully drawing the animal from its shell after freezing and subsequent thawing. Wet weight was measured after washing away feces and light blotting of the

tissues. Body condition was determined by the ratio of wet weight:shell length.

Living macrophytes and macroscopic detritus were collected from each enclosure at the beginning and at the end of the experiment. Four replicates were taken from 25 cm square quadrats into nylon bags (3.0 mm mesh) for determination of above-ground biomass. Individual samples were divided into green <u>Thalassia testudinum</u> blades and detritus (senescent blades and blade fragments). The only other macrophytes collected were the seagrasses <u>Syringodium filiforme</u> and <u>Halodule Wrightii</u> found in very small amounts, and an occassional calcareous green alga <u>Rhipocephalus phoenix</u>. The above-ground fractions were dried at 80°C to constant mass and weighed. The calcareous alga was not included in analysis of macrophytes because of the large bias created in dry weight and because <u>R. phoenix</u> is not consumed by juvenile conch.

Sediments to 5 cm depth were sampled with a 3.5 cm diameter core tube, 1 sample per enclosure. These samples were frozen until the laboratory analyses were performed. Sediment organic content was determined by drying a subsample of approximately 100 g wet weight at 80° C to constant mass and incineration at 500° C for 4 hours. Organic content was quantified as the percent difference between dry weight and ash-free dry weight. Another subsample of approximately 50 g was analyzed for granulometric properties. The sample was washed to remove salts and to extract the silt-clay fraction (< 62 um) which was analyzed with standard pipette procedures (Folk 1966). The sand fraction (> 62 um) was analyzed using standard Ro-Tap procedures. Product-moment statistics were generated for mean grain-size and sortedness.

RESULTS

Habitat Characteristics

Juvenile conch were transplanted to 4 different habitats types based upon macrophyte biomass: zero, low, moderate, and high biomass sites (Table 1). Sediment grain-size at the 8 sites varied from 1.15 to 2.56 \emptyset ; however, there was no significant difference in the mean values (ANOVA, F = 2.26, p > 0.05), and all are classified as fine to medium sand. Similarly, there was no difference in sediment sorting coefficients (F = 2.09, p > 0.05), with all sites except the bare sand (C3) in the poorly sorted range. Significant differences occurred in sediment organic content (F = 15.97, p < 0.001) with highest values at the high biomass site (L2) and lowest at the sand site (Table 1). There were no significant differences in sediment organics among the other sites with low or moderate biomass.

At the beginning of the experiment, t-tests showed that there were no significant differences in biomass of either seagrass or macrodetritus between the two cages at any site (p > 0.05). Analysis of variance for log-transformed biomass data indicated that macrodetritus varied significantly (F = 76.48, p < 0.001) at the 8 sites , but there were no significant differences in mean values for the 3 stations classified as low biomass (N1, L3, W1) or for the 3 moderate biomass sites (C1, C2, L1) (Neuman-Keuls test, p > 0.05). Macrodetritus was more abundant at the high biomass site (L2) than at any other site (p < 0.05), and zero at the sand site (C3)(Fig. 2). The same pattern occurred with living seagrass biomass, except that site C1 had significantly higher biomass than the other moderate biomass

sites, but less than that found at the high biomass location (L2)(ANOVA, F = 58.12, p < 0.001; Neuman-Keuls test, p < 0.05).

For analysis of seagrass and macrodetritus standing crops at the beginning and end of the experiment, paired comparison analysis of variance was conducted, where cage and time effects were examined. Cage effects were significant only at N1 where enclosure 2 had a higher biomass of living seagrass than enclosure 1 (F = 7.46, p < 0.05). There were no cage effects within sites for macrodetritus $(p \rightarrow 0.05)$. Significant differences with time were found at L1 where detritus decreased (F = 13.22, p < 0.005), while living seagrass increased with time (F = 20.15, p < 0.001). Seagrass increased also at C2 (F =23.12, p < 0.001) and at L3 (F = 34.89, p < 0.001). There were no other significant effects of time for either macrodetritus or seagrass biomass. Temperature at the initiation of the experiment in April was approximately 25°C. In July and August temperature reached 30.5°C but tidal variation (to 2.0°C) was strong at all sites. Mortality

Mortality at experimental sites with natural populations of conch was low, ranging from zero at site C1 to a total of only 4 individuals during the last period at site N1 (Fig. 3). Mortality at the sites with moderate seagrass density and no resident conch populations (L1 and C2) were also low, less than 10 individuals of the total population in any one experimental period, and decreasing with time. Mortality was high at all other sites, with a need for heavy replacement after the first experimental period. By the end of the experiment 61 animals had died at the high biomass site (L2) and 61 had died at 1 of the low biomass sites (L3). Mortality was relatively constant over

the 3 experiment periods at both of these stations. The transplant experiment was terminated at the sand site (C3) after 95 days because of rapidly accelerating mortality.

Two-way ANOVA for the transformation log10(mortality + 1) resulted in a significant interaction of experimental period and site (F = 17.838, p < 0.001). This is the result of increasing mortality at C3 and W1, while other sites had relatively constant rates of mortality. One-way ANOVA showed significant site differences in mortality rate for all 3 periods (F = 24.282, p < 0.001 for period 1; F = 5.672, p = 0.013 for period 2; F = 6.343, p = 0.009 for period 3). For period 1, non-significant differences in mortality (zero) were found at C1, N1, and W1 (Neuman-Keuls test, p> 0.05); these sites were different from all others sites (p < 0.05). During the later experimental periods, there were large within-site differences in mortality rates. resulting in lack of significant differences among station pairs. In general, however, mortality was high except at sites with resident conch populations and/or moderate seagrass biomass. Growth

During all experimental periods there were significant site variations in conch growth rates (Fig. 4). Two-way ANOVA for log-transformed growth rates resulted in a significant interaction term between growth period and site (F = 21.872, p < 0.001). This was a consequence of rapid growth rates at site W1 (L) declining rapidly after the first period. Growth rates decreased with time at most of the stations, but the decrease was extreme at W1. Because of the interaction, one-way ANOVA was performed for each growth period to test for site effects. In all cases the effect of site was highly significant (F = 43.26, p

< 0.001 for period 1; F = 111.77, p < 0.001 for period 2; and F = 78.84, p < 0.001 for period 3).

During the first growth period, low biomass site W1 and moderate biomass site C2 yielded growth rates that were not different from each other (Neuman-Keuls test, $p \rightarrow 0.05$) but were higher than all other sites (p < 0.05). During this period, growth rates were different in the 2 cages at W1 (Student's ttest, t = 3.775, p < 0.001), but no other significant differences between cages occurred ($p \rightarrow 0.05$). There were no significant differences between growth rates at moderate biomass sites C1 and L1, or between sites N1 (L) and L2 (H) ($p \rightarrow 0.05$). Rates at sites L3 (L) and C3 (sand) were different from all other sites (p < 0.05).

During period 2, growth rates increased slightly at C1 (M), C2 (M), and N1 (L), but decreased by at least 50% at the other five sites. Rates at C3 (sand), W1 (L), L3 (L), and L2 (H) were all low and not different (p > 0.05), with negative growth (shell erosion) occurring at both L2 and L3. All other sites had higher growth rates and all were significantly different. A significant difference in growth rates between cages at C3 (t = 2.862, p < 0.01) was the result of new animals being introduced in the rebuilt cage 1 during this period; however, growth rates were low in both cages.

Growth rates during period 3 were lower than those during period 2, except at stations W1 (L) and L2 (H) where many animals had been replaced due to high mortality. Rates at W1, L1 (M), and L2 were low and not different (p > 0.05). Growth rates at all other sites were different . Strongly negative growth rates occurred at station C3 (sand) and L3 (L). As in period 2,

highest growth rate was observed at the moderate biomass site C2 where there is no resident conch population. There were no significant cage differences at any of the sites during this period (p > 0.05).

High growth rates at sites C2, C1, and N1 were associated with high body condition (Table 2). Predictably, condition was low in the bare sand habitat and other sites where survivorship was low (e.g., L3, W1), and there were various site differences (ANOVA, F = 15.03, p < 0.001) (Table 2). Despite high mortality and low growth rate at the high biomass site (L2), condition factor at that site was not different significantly from sites with natural conch populations.

Comparing rates of mortality and growth, a pattern emerges: low growth occurred with high mortality at sites C3 and L2. Accelerating mortality and rapidly declining growth rates were found at W1 and L3, while mortality remained low and growth rates high at C1, C2, and N1. At L1, mortality was low but growth declined from a high rate in the first period. Simple linear regression indicated that mortality rate was inversely related to growth rate (r = 0.899, F = 21.16, p < 0.01).

DISCUSSION

The results of this study demonstrate that the absence of juvenile queen conch may be a function of recruitment limitation or habitat quality. Despite the fact that groups of stations were chosen for equivalent sediment, depth, and macrophyte characteristics, significant differences in survivorship and growth rates occured. After the first growth period, transplants to only 1 non-conch site resulted in survivorship and growth

rates equivalent to those in sites with resident conch populations.

The mechanisms which regulate success of juvenile conch in any 1 habitat remain essentially unknown; however, trophic mechanisms may be involved. Adult and subadult queen conch are generally considered to be herbivores (Robertson 1961, Randall 1964, Hesse 1976), but recent data on conch living in seagrass beds identify seagrass detritus as the primary food source for juveniles (Stoner 1989a). The failure of conch to survive and grow at the moderate biomass site L1. for example, is likely to be related to the depletion of detrital biomass. Other field experiments have shown that juvenile conch can have a major influence on detritus and other characteristics of the benthic environment, and much of the benthic productivity is removed by grazing (Stoner 1989a,b). Habitats with and without conch, therefore, should not be compared directly. Environmental factors other than macrophyte biomass and detritus, such as epiphyte biomass, algal content of the sediments, and dynamic processes such as seagrass and detritus production may need to be examined to predict distribution of conch populations.

High levels of mortality at certain sites may be related to predation, starvation, or increased susceptibility to disease. Hermit crabs were found frequently in empty shells of conch in the enclosures; however, lack of growth, low body condition, and empty and unbroken shells suggest that <u>Paguristes</u> spp. acted primarily as a scavenger or attacked animals weakened by poor nutrition. The giant hermit crab (<u>Petrochirus diogenes</u>), was observed in empty shells in a few cases, and is known to be an active predator on conch (Randall 1964). The tulip snail

(Fasciolaria tulipa) was observed attacking juvenile conche 3 different times. A few apple murex (<u>Murex pomon</u>) were seen in the enclosures but as reported by others authors (Jory and Iversen 1983, Iversen et al. 1986), they were not observed attacking live conch.

High mortality, particularly during the third experimental period at sites such as Windsock Cay (W1), may result from prey being concentrated in small areas. Transplants to enclosures in an area without a natural conch population may result in higher predation rates than those in areas where conch are present in the surrounding habitat. Because of potential density-dependent effects on predation rate and uncertainty in the sources of mortality, we are conservative in our interpretation of the mortality data.

To eliminate density-dependence in growth rates, dead conch were replaced with healthy individuals. High mortality which occured at other sites during the third period (L2 and L3), introduces a source of bias because the replacement conch probably continued to grow using stored reserves or were better able to find food remaining in the cages. Growth rates in the areas with high mortality, therefore, are probably over estimated and site differences may be greater than those observed.

Growth rates found in the natural conch habitats (C1 and N1), between 0.1 and 0.2 mm/day, were similar to those determined by a tag-recapture method at C1 during the summer 1985 (0.12 mm/day)(Wicklund et al. 1988), and the summer 1987 (0.10 -0.15 mm/day)(Stoner 1989a). Density-dependent growth rates were reported for 1-year old conch held in enclosures at Lee Stocking Island, but unenclosed conch and conch held at $2.0/m^2$ had

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equivalent growth rates (0.10 to 0.17 mm/d)(Stoner & Sandt 1988, Stoner 1989a). These results suggest that enclosures used in this experiment did not inhibit growth in the test animals.

Growth rates at the natural conch sites tested in this study were similar to those reported from Los Roques, Venezuela. Growth curves for tagged conch, between 85 and 105 mm in shell length, provided mean growth rates of 0.16 mm/day (Laughlin & Weil 1982). For conch 90 mm Brownell et al. (1977) reported growth rates of 0.14 mm/day. Lower rates obtained here suggest that the habitats without resident conch (except C2), were less than optimal.

Abundance of macrophytes does not necessarily make a superior habitat. Site L2 had a thick accumulation of detritus and high seagrass shoot density, but conch transplanted to that site had high mortality and low growth rates. Randall (1964) noted that young conch may not be able to move readily through dense stands of <u>Thalassia testudinum</u> and <u>Syringodium filiforme</u>, and consequently, they are not found there. In a recent investigation at Lee Stocking Island 1 and 2-year old queen conch were observed at maximum summer densities in seagrass beds with approximately 65 g dry wt/m² of <u>Thalassia testudinum</u> and 100 g dry wt/m² of detritus. Density of juvenile conch decreased rapidly with higher or lower macrophyte abundance. Behavioral experiments showed that juvenile conch are proficient in finding macrophyte biomass of optimal density (Stoner & Waite, in review).

The fact that 1 site with no resident juvenile conch (C2) produced high growth rates and survivorship supports the hypothesis that the distribution of queen conch is recruitment

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limited in certain areas. Recruitment limitation may take different forms; Pelagic Larvae may not be dispersed to the area, settlement may not occur, or post-metamorphic survivorship may be low. Also, it is known that juvenile queen conch make ontogenetic migrations from one habitat type to another (Weil and Laughlin 1984; Stoner et al. 1988); therefore, some seagrass areas with good characterisities for juveniles may be too distant from the primary site of larval settlement to permit benthic dispersal.

High rates of survival and growth site C2 also lend support to the hypothesis that outplanting of hatchery-reared juveniles can be a successful mechanism for enhancing or rebuilding conch populations in areas where fishing is heavy (Berg 1976, Brownell et al. 1977). Experimental releases of young conch, however, have resulted in very rapid disappearance and/or mortality (Appeldoorn & Ballantine 1983, Appeldoorn 1985). Until the mechanisms of distribution are known, simple, small-scale transplanting will prove useful in predicting the liklihood of outplant success in specific localities (see Stoner & Sandt 1988).

Experimentation reported here indicates that populations of juvenile queen conch may be recruitment limited in certain locations, and provides insight into some of the conditions that characterize optimal habitat for the species. Data on larval abundance, settlement, and early post-metamorphic survivorship and growth will be needed to elucidate the poorly known mechanisms for habitat association in queen conch.

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Table 1: Habitat characteristics of eight sites to which juvenile queen conch were transplanted. Depth is the mean at low water. Values for sediments are mean \pm standard deviation (n = 2). $\stackrel{*}{}$ and $\stackrel{+}{}$ indicate mean values for organics which are not different statistically (ANOVA and Neuman-Keuls test; p < 0.05).

Site	Seagrass Biomass	Depth (m)	Sediment Grain-size (0)	Sediment Sorting (0)	Sediment Organics (%)
СЗ	Zero	1.3	1.50±0.02	0.84±0.01	2.38±0.33 ⁺
N1	Low	2.3	1.52±0.10	1.14±0.06	2.68±0.14 ^{*+}
LЗ	Low	2.2	2.02±0.30	1.08±0.20	3.66±0.33 [*]
W1	Low	2.0	1.82±0.20	1.47±0.28	3.83±0.47 [*]
C1	Moderate	3.6	2.56 ± 0.29	1.39±0.22	3.76±0.33 [*]
C2	Moderate	3.7	1.15±0.11	1.62±0.19	2.80±0.33 ^{*+}
L1	Moderate	3.4	2.26±0.23	1.40±0.23	2.92±0.32 ^{*+}
L2	High	3.7	2.40±0.19	1.04±0.07	5.36±0.48

Table 2: Condition factor of juvenile queen conch transplanted to eight different sites. Values are mean ± standard deviation (n = 15). Vertical bars indicate similarity of means (ANOVA and Neuman-Keuls test; p < 0.05).</p>

Site	Seagrass Biomass	Condition Factor	
C2 C1 N1 L2 L1 L3	Moderate Moderate Low High Moderate Low	$\begin{array}{c} 0.257 \pm 0.030 \\ 0.246 \pm 0.031 \\ 0.227 \pm 0.031 \\ 0.216 \pm 0.036 \\ 0.208 \pm 0.025 \\ 0.188 \pm 0.036 \end{array}$	
W1 C3	Low Zero	0.188 ± 0.034 0.180 ± 0.030 0.165 ± 0.020	

LIST OF FIGURES

- Figure 1: Map showing the locations of the transplant sites in the southern Exuma Cays, Bahamas.
- Figure 2: Standing crop of <u>Thalassia testudinum</u> and macrodetritus at the sites where juvenile queen conch were transplanted. Each sample represents an area 25 by 25 cm. Histograms are mean values found in the enclosures at the beginning and end of the experiment. Error bars are ± standard deviation. Note the change of scale for macrodetritus at station L2.
- Figure 3: Relative mortality of juvenile queen conch at the eight transplant sites during the three growth periods. Histograms represent mean mortality for the two enclosures at each site ± standard deviation.
- Figure 4: Growth rates for juvenile queen conch at the eight transplant sites during three growth periods. Values are mean ± standard deviation. The black bars represent growth rates at sites with resident conch populations.



C





MORTALITY (% of Population)



0

GROWTH (mm/day)