BARNACLE RECRUITMENT ON ARTIFICIAL CYLINDERS: AN INTERACTION BETWEEN LARVAL SUPPLY, OCEANOGRAPHIC CONDITION AND SMALL SCALE PROCESSES

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INTRODUCTION

Most marine invertebrates show at least one planktonic larval stage as part of their life cycle. Those larvae are the main source of new individuals to populations, and consequently, marine communities are vulnerable to their return. Larval recruitment rates are known to be able to regulate dynamics of the marine communities. Variation of these rates can directly influence the strength of ecological interactions on benthic environments (Gaines & Roughgarden 1985). Recruitment is a function of larval supply. However, it is not possible to establish a direct relationship between them in every situation (Rilov *et al.,* . 2008). Larval supply to coastal communities is close connected to oceanographic phenomena, and larva interaction with them (Roughgarden *et al.,* ., 1988; Shanks 1995). Although, recruitment works in its dependency, other factors may result in recruitment variation. Factors acting in reduced temporal and spatial scale might be responsible for this disconnection between larval supply and recruitment. Larval response to environmental conditions during settlement can also modify recruitment rates. Hydrodynamics influence processes, larval supply and distribution by aggregation patterns and interaction with larval behavior, but also with larval response to settlement and capacity to fix in determinate regimes (Crisp 1955). Barnacles are examples of all the fundaments described above and are excellent models to be used in studies that couple pelagic and benthic processes. Investigations involving larval supply and recruitment may help to comprehend the dynamic of invertebrate marine communities.

OBJECTIVES

The aim of this study was: (i) to investigate experimentally the spatial and temporal patterns of larval supply and recruitment over two distinct oceanographic conditions; (ii) to examine barnacle recruitment patterns in centimeter scale on artificial cylindrical surfaces; (iv) to compare resultant patterns of larval supply and recruitment.

MATERIAL AND METHODS

Study Area. Experiments were realized at Praia do Farol, Ilha do Cabo Frio, Arraial do Cabo, Rio de Janeiro State. Praia do Farol is a sand beach, surrounded by rocky shores and a Sargassum bed over a beach rock. Both contribute for a great larval supply to the study area. This beach is located at a tropical region, however, it is directly influenced by two meteorological - oceanographic phenomena, Northeast Wind-Upwelling System and Cold Front-Relaxation System (Franchito *et al.,* . 2007). Those phenomena are able to alter local hydrodynamic characteristics. The first one is characterized by offshore transport of surface waters, and thus, upwelling of cold rich waters caused by wind from N - E and N - W quadrants blowing over sea surface. This is the most common condition at the study region, with duration of 5 - 15 days. The second feature is characterized by S - W and S - E winds causing opposite transport of warm surface waters to onshore direction. Cols Fronts are considered the relaxation condition for Cabo Frio upwelling system, and they occur with a frequency of 7 - 15 days, and average duration of 3 days. Both features alternate temporally all year around. Water temperature at Praia do Farol varies from 16oC to 28oC (Gonzalez - Rodrigues *et al.,* .., 1992).

Biological Model. Cirripedia was used as biological model. Barnacles are permanent components of marine benthic communities. Its larval supply and recruitment are frequently associated to oceanographic dynamics. Barnacle larvae are known to respond to hydrodynamic condition for swimming and settlement behavior. Barnacle first recruits, cypris larvae were the focus stages during the study. Besides seasonality, Cirripedia reproduce during all months of the year, thereby larva is generally found in considerable amounts in plankton. Although, sampling was realized during known recruitment season.The study was done quantitatively and no distinction among species was done.

Sampling Tools. Recruitment was measured over cylindrical PVC external surfaces (30cm height and 6,5 cm diameter). Cylindrical surface was chosen based in its better sampling efficiency in systems under hydrodynamic flux, and also because it permits natural manipulation of hydrodynamic condition around it (Vogel 1994; Rittschof 2007). Cylinders were installed perpendicular to the main sea current, and we imaginary divided cylinder surfaces in 4 sides for recruitment measurements. Sides were subjected to a singular hydrodynamic condition depending on current direction and they had specific position in relation to supporting units. Larval supply was quantified using cylindrical plankton traps (Yund *et al.,* .. 1991). Each trap was build using 4 Falcom centrifuge tubes (12 cm high; 3,5cm diameter), pilled one over the other and connected by 3 peaces of plastic tube. Larva was captured and preserved by 37% formaldehyde solution disposed in the last tube.

To asses a potential depth gradient in recruitment larval processes, traps and cylinders were disposed close to surface layer, 1,5 m deep, and to the bottom, 5 meter deep. To verify possible horizontal gradient in larval supply, the traps were disposed in 4 positions following the cardinal points. Multi - experimental units were built to make field installation of sampling instruments feasible and to permit evaluation of desired gradients. We build 5 units for surface gradients and 5 for the bottom ones. The structures were disposed in separate pars (1 surface, 1 bottom), randomly close to *Sargassum* sp bed. Surface multi - experimental unit was build using strengthened PVC tube (40 cm height; 20 cm diameter). The main tube supported 4 PVC arms (50cm long; 20 cm diameter), used to hold the sampling instruments. The four arms were cross disposed following the cardinal points (north, N; south, S; east, L; west, O), and permitted establishment of the horizontal gradient. Each arm could hold one plankton trap and one cylinder simultaneously by the PVC connections in its extremity, as a total of 8 instruments for each unit. We hanged the main PVC structure using nylon ropes and foam buoys anchored with cement weight. Bottom multi - experimental units had the same main PVC structure and supporting arms. However, its dimension was 1 m high, cement was placed inside the tube and it was berried 40 cm in the sand to hold it still.

Environmental conditions Sampling conditions and respective dates were chosen randomly from the end of March to August 2008, based on weather broadcast for the study area. We followed online weather prediction obtaining information for the study area from Centro de Previsão de Tempo e Estudos Climáticos, Instituto Nacional de Pesquisas Espacias-CPTEC/INPE. As soon as a strong *Cold Front System* was known to be reaching the region, we would start the experiments. We attended the other meteorological condition, *Northeast Wind-Upwelling System*, using the same method. Wind velocity and direction were registered by Automatic Meteorological Station, located in land close to the study field which provided hourly data. Wind direction standards used: 0o North; 90º East; 180º South; 270º West. Local surface and bottom water temperature were obtained weekly by field measurements.

Sampling Experimental Design and Field Proceediment To evaluate larval processes as a function of the two meteorological - oceanographic systems, we realized 6 - days field experiments using all sampling structures described above. Thee following factors were manipulated: Oceanographic Condition: sampling experiments were realized during Cold Fronts, and Northeast Wind; Event: to represent the conditions desired, we have chosen three events for each system randomly through time; Sampling Depth: samples were obtained in two depths, surface layer and bottom, to verify a potential vertical gradient in larval processes; Geographic Orientation: trying to represent variability occurring horizontally in the water mass, we sampled in a 10 - centimeters gradient, cross placing sampling instruments in four positions (North, South, East, West); Cylinder Side: this factor was manipulated just for recruitment, as we divided the cylinder surface in four different sizes to observe recruitment gradient over it. This treatment was made to assess a potential larval response to contrasts in flux around the cylinder, or recruitment result as function of the same purpose, sides were established in function of the geographic orientation (Side A, Side B, Side C, Side D).

Statistical Procedures Recruitment and Larval supply data were analyzed using the following steps. Variables obtained were: i. number of recruits per cylinder side, or number of recruits per cylinder, for; ii. number of larvae per trap for larval supply. We used nested factorial analysis of variance (ANOVA) with balanced replicates to evaluate the effect of manipulated factors on larval supply and recruitment. Number of factors was established according to sampling design. Data was LOG(x+1) transformed to attend test premises, normality and homogeneity of variances. The premises were verified using Kolmogorov - Smirnoff Test (K - S) and Cochran Test, respectively. All proceeding were realized using Statistica Software 5.0. An = 0,1 was used in function of high number of factors manipulated by the experimental design to increase test power. ANOVA model: (5 - factor) factor 1, "oceanographic condition"(OC), fixed with two levels (*Cold Front Relaxation System, Northeast Wind - Upweling System*); factor 2, "event"(E), random and **nested** in "oceanographic condition", with three levels (event 1, event 2, event 3); factor 3, "sampling depth"(D), fixed and orthogonal, with two levels (Surface, Bottom); and factor 4, "geographic orientation"(O), fix and orthogonal, with four levels (North, South, East, West); and factor 5, "cylinder side"(S), manipulated just for recruitment, fixed and **nested** to last factor, and with four levels (side A, side B, side C, side D), e each level with 5 replicates. Environmental condition data were analyzed using only descriptive statistics and graphic patterns, including average data and respective standard deviation when necessary.

RESULTS AND DISCUSSION

Environmental Conditions Great variability was observed in wind behavior during each 6 - day sampling event, and also similar average velocity and direction for both oceanographic conditions. During Cold Front - Relaxation events, wind velocity was relatively lower compared to the opposite condition, specially, when wind remained from S - O and S - E directions, matching the common characteristics of these phenomena. On Northeastern Upwelling Wind samplings, wind intensity reached higher values and average when from N - O and N - E directions, remaining stronger for longer time periods as usual at the study area during these conditions (Franchito *et al.,* . 2007 ab). Week water temperature was 23,5oC average for both conditions, and for surface and bottom water. However, it was not detected by weekly measurements, upwelling occurred at close areas on Northeastern Wind events, and temperatures remained under 19ºC (personal observation). Despite the great variability, these conditions match to the expected characteristics of the meteorological - oceanographic features studied (Franchito *et al.,* . 2007 ab). Even that sea temperature did not varied in function of condition, wind reproduced the desired condition for experimental manipulation.

Larval supply and Recruitment

Higher cypris larval supply was registered on *Cold Front* events, compared to the opposite system. Differences in supply magnitude between conditions averaged on 10 larvae per trap. Contrasts among sampling events were present in both situations. Surface supply was higher than bottom supply, and horizontal spatial gradient was not as relevant. When analyzing particular situations for each condition separately, on *Cold Fronts*, first event differed from the others. It was apparently similar to *Northeast Wind* events, with number of larvae per trap lower than 3 individuals. Depth gradient varied among orientations in this event and it was not as steep as the other events. For *Northeast Wind* condition, contrasts between surface and bottom supply were not so evident, and small variation between depths was detected. First and Second events presented some variability among horizontal traps. According to ANOVA results, the following factors were able to explain larval supply variability: ‘oceangraphic condition’ ($F = 5{,}35$; $p = 0{,}0818$); ‘event’ ($F = 130{,}75$; $p < 0{,}000$); ‘depth’ ($F = 11{,}29$; $p = 0{,}0283$;); and the interaction ‘event’ versus ‘depth’ ($F = 14{,}96$; $p < 0{,}000$). These results support later data interpretation. Statistical interaction reflects the fact that, during one event in both oceanographic condition, depth gradient was not statistical significant.

In agreement with observed cypris supply, recruitment was clearly greater during Cold Front events compared to with *Northeast Wind* events. Recruitment in *Northteast Wind* events was very low and close to zero recruits per cylinder. Data variation was also statistically significant for recruitment, and oceanographic condition contrasts were identified by ANOVA test too ($F = 7{,}36$; $p = 0{,}0533$). This test pointed out some statistical interaction between factors. Each condition showed different tendencies related to some of the factors investigated. Following larval supply, significant contrasts among sampling events were observed for recruitment ($F = 166{,}24$; $p < 0{,}000$). For Cold Fronts, first event showed least recruits, and third events the most. For *Northeast Winds*, the last event showed greater recruitments compared to the other two. Small variability was registered for recruitment between depths in the water column. Number of recruits among surface and bottom cylinders was very similar ($F = 0{,}5396$; $p = 0{,}5034$). This pattern differed from supply, which was greater in surface waters. In some situations, a depth contrast was present, for example in *Cold Front* condition, but it varied among sides, orientation and events (statistical interactions: “D * E”: $F = 9{,}00$; $p < 0{,}000$; “MC * D * S: $F = 2{,}12$; $p = 0{,}0330$; “MC * D * O”: $F = 2{,}89$; $p = 0{,}0797$), resulting in a complex pattern. Depth variability was not sufficient great to explain all data variation in recruitment, its relevance dependent on factor assessed. Non - significant variation was found in number of recruits settled on cylinders located in different horizontal position ($F = 2{,}5313$; $p = 0{,}1063$) for cold front experiments. In this situation, if we observe cylinder sides, recruitment varied among orientation, but it didn’t show a defined pattern for all sides ($F = 2{,}72$; $p = 0{,}0910$). Recruitment varied among cylinder sides, for *Cold Front* situations ($F = 2{,}24$; $p = 0{,}0244$). Due to lower number of recruits found on cylinder surface during *Northeast Wind* events, side variability was not statistical significant. So, side variation depend on oceanographic condition, and consequently an statistical interaction was found ($F = 1{,}85$; $p = 0{,}0661$). If we sum total number of recruits found per cylinder and consequently despise treatment ‘side’, we may graphically observe that observed recruitment patterns is maintained.

Our results showed that barnacle recruitment was significantly affected by meteorological - oceanographic phenomena. Contrasts between environmental conditions were dependent on differences from larval supply. Recruitment pattern at the study area was similar to dynamics observed in other Upwelling Systems. It follows the model proposed by Roughgarden *et al.,* . 1988, where greater barnacale recruitment occurs during Relaxation periods, in our situation specifically *Cold Front* events. Besides later patterns consistency, great variability was detected for recruitment among sampling events, and for both oceanographic conditions. This might be an evidence of vulnerability of ecological processes to environmental variability and stochastic characteristics, but also, its intimate connection (Shanks, 1995; Narváez *et al.,* . 2006). Recruitment did not follow larval supply gradients in every situation manipulated. A direct relationship could not be established between the two processes. For example, depth contrasts found for cypris supply between water column vertical positions disappeared in recruitment. Small scale processes might be directly affecting the transition among environments and may be responsible for modification of patterns from water column to benthic environment. We believe that hydrodynamic condition may be one of these responsible factors (Rittschof *et al.,* . 2007). Surface waters in the study area have high current velocity because of the influence of the two systems. On one hand this may provide a greater larval supply, however it may difficult larval settlement increasing larval detachment from cylinder surface (Crisp, 1955; Abelson & Denny 1997). Cylinders sides showed variable recruitment, but a complex and undefined pattern was detected. Another evidence of effect of small scale patterns acting on recruitment.

CONCLUSION

In conclusion, different oceanographic conditions are able to influence larval supply and consequently generate recruitment patterns in Cirripedia. Upwelling areas may show similar barnacle recruitment patterns, and Upwelling - Relaxation model may be applied to Cabo Frio Upwelling System. Recruitment is extremely dependent on larval supply and the oceanographic processes driving it. However, the relation between recruitment and larval supply is not direct, and factors acting on small spatial and temporal scales may modify this relation. Barnacle recruitment is a consequence of larval supply, oceanographic condition and small scale processes.

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