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within the Cas Cay/Mangrove Lagoon and Great St. James Marine Reserves, St. Thomas USVI

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ABSTRACT

Postlarval settlement of the commercially important Caribbean spiny lobster, *Panulirus argus,* was monitored at five sites within the Cas Cay/ Mangrove Lagoon and Great St. James Marine Reserves on the southeast side of St. Thomas, United States Virgin Islands. Over a period of one year, a total of 202 postlarvae (pueruli = 57; juveniles = 145) were collected from 270 samples for a combined mean annual CPUE of 0.07 (± 0.19) pueruli/collector/ day for all sites. Overall CPUE was low despite location within the protected waters of the marine reserves. The highest settlement occurred at Nazareth Bay, which had a mean annual CPUE of 0.18 (± 0.35). Month to month variability was low, although there appears to be a seasonal peak occurring in late spring (May). The highest recruitment levels occurred between new moon and first quarter moon phases. Postlarval settlement declined among common sites between 1992 - 1993 (combined mean annual CPUE = 0.20 ± 0.29), 1997 - 1998 (combined mean annual CPUE = 0.15 ± 0.30) and 2002 - 2003 (combined mean annual CPUE = 0.07 ± 0.19). Spatial differences in settlement over time indicated that pre-settlement pueruli were most likely influenced by changes in habitat, and water movement.

KEY WORDS: Recruitment, catch per unit effort, pueruli

Variaciones Espaciales y Temporales en el Establecimiento de las Etapas Post Larvales de la Langosta Espinosa, *Panulirus argus*, entre 1992 y 2003 dentro de la Laguna de Cas Cay/ Mangrove y de la Reserva Marina de St. James, St. Thomas, USVI

El asentamiento postlarval de la comercialmente importante langosta espinosa, *Panulirus argus*, fue monitoreada en 5 sitios en Cas Cay/Mangrove Lagoon y en la reserva marina Great St James en el lado sureste de St Thomas, Islas Virgenes Estadoudinenses. Un total de 202 postlarvas (pueruli = 57;juveniles = 145) fueron colectadas de 270 muestras para un promedio de captura por unidad de esfuerzo (PCPUE) de 0.07 para todos los sitios. En general, los promedios del CPUE para todos los sitios fueron bajos a pesar de localizarse dentro de las aguas protegidas de la reserva marina. La mayor parte del asentamiento ocurrio en Nazareth Bay, cual obtuvo un promedio de CPUE de 0.17 (SD = 0.35). La variabilidad entre mes fue baja con un valor maximo tarde en la primavera (Mayo). Los maximos valores del reclutamiento ocurrieron en luna nueva y en el primer cuarto creciente de la luna. Se registro una disminucion en los promedios anuales del asentamiento postlarval en los sitios estudiados entre 1992 - 1993 (PCPUE = 2.65 pueruli), 1997 - 1998 (PCPUE 0.16 pueruli) y 2002 - 2003 (PCPUE = 0.07 pueruli). Las diferencias entre las localidades de asentamiento atraves del tiempo indicaron que la abundancia del pueruli de la etapa de preasentamieneto pueden estar influenciada por cambios en el habitat, y el movimiento y la calidad del agua.

PALABRAS CLAVES: Langosta, asentamiento postlarval, USVI

INTRODUCTION

Spiny lobsters (Palinuridae) are among the most economically important crustaceans in the world (Olsen et al. 1975). The Caribbean spiny lobster, *Panulirus argus*, supports an important commercial and recreational fishery in the U.S. Virgin Islands (USVI). Effective management of such a fishery not only requires adult stock assessment but also identifying trends in settlement and recruitment. Spatial and temporal variability in recruitment is characteristic of many invertebrate fisheries (Butler and Herrnkind 1997). Therefore, settlement and early post-settlement processes that influence recruitment demand great attention. The influx of postlarval lobsters can be monitored using modified Witham collectors (Witham et al. 1968). These collectors are useful in determining the relative abundance of pueruli in an area and have been used to make general comparisons across areas (Witham et al. 1968).

Over the last decade, spatial and temporal trends in pueruli settlement and abundance has been studied using modified Witham collectors around St. Thomas (both inside and outside the Inner Mangrove Lagoon, Cas Cay/ Mangrove Lagoon, and St. James Marine Reserves). Studies were previously conducted in 1992 - 1993 (Quinn and Kojis 1997), and 1997 - 1998 (Kojis et al. 2003).

The objectives of this study were to examine current spatial and temporal variations in *P. argus* pueruli settlement and relative abundance at previously studied sites within marine reserve habitats and compare trends in relative abundance and settlement of pueruli between 1992 - 1993, 1997 - 1998, and 2002 - 2003.

MATERIAL AND METHODS

Pueruli collectors were modified from the original design used by Witham et al. (1968). Collector frames were made from 1.90 cm closed PVC pipes that measured 40.5 cm x 40.5 cm, and comprised of four crossbars connected by 90º elbows. For each collector, four "hogs hair" air-conditioning filters were cut into 40.5 cm x 61 cm pieces, folded lengthwise with the webbed backing material to the inside, slipped over each crossbar on the PVC ladder frame, and secured. Each collector was moored with two concrete cinder blocks and suspended in the water column by a sub-surface buoy. At each site the collectors were spaced approximately 10 m apart.

On 4 June 2002, two pueruli collectors each were deployed at five sites within the Cas Cay/Mangrove Lagoon and Great St. James Marine Reserves on the southeast side of St. Thomas (Figure 1). Study sites in 2002 - 2003 were similar to previous studies by Quinn and Kojis (1997) and Kojis et al. (2003). Of the sites sampled in 2002 - 2003, all were identical to the sites sampled by Kojis et al. (2003) in 1997-98, however, only the Mangrove Lagoon and Great St. James Island sites were sampled in 1992 - 1993. Two collectors were used at each site in 1992 - 1993, while three collectors were used in 1997-1998.

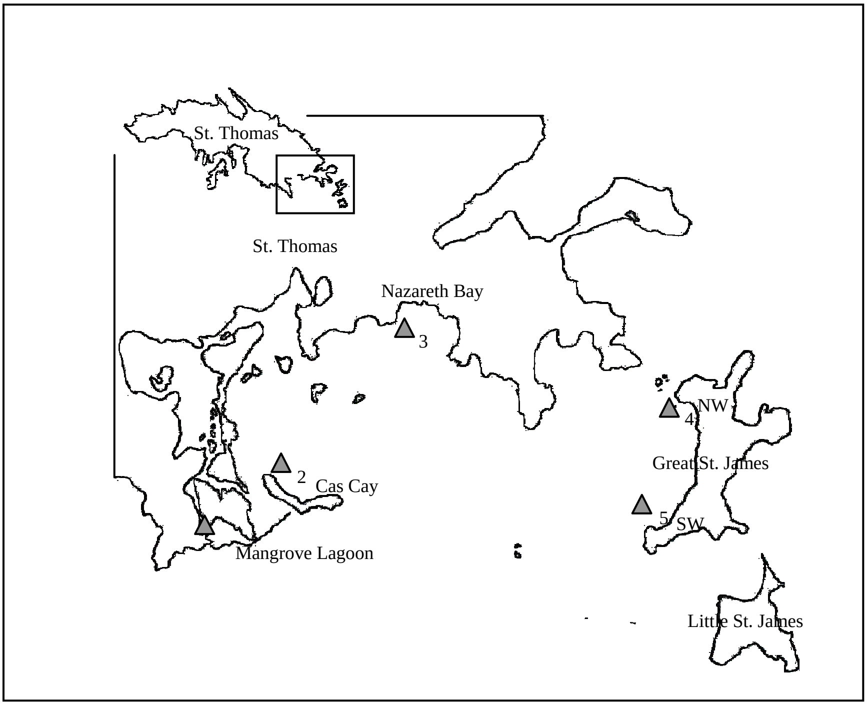

Figure 1. Map of the east end of St. Thomas showing the locations of the five pueruli collection sites.

The Mangrove Lagoon site (18º18.3' N, 64º52.5' W) was located in a shallow protected channel in the inner lagoon of the Mangrove Lagoon Marine Reserve. Due to its enclosure, the inner lagoon experiences limited flushing and current. Conversely, the Cas Cay site (18º18.5' N, 64º 52.1' W) was located in the outer Mangrove Lagoon Marine Reserve and experienced heavy wind and moderate wave action. Although both sites were essentially mangrove habitats the substrate at the first was a dense macroalgal plain while the latter a dense seagrass bed. The collectors at both sites were positioned approximately one meter below the surface in 1.5 - 2 m of water.

The Nazareth Bay (18º 19.1'N, 64º 51.4'W) and southwest Great St. James (18º18.4'N, 64º 50.1'W) sites were positioned over sparse seagrass beds approximately 100 m from the rocky shoreline. The collectors at both sites were suspended 3 m below the sea surface in approximately 6 - 11 m of water.

Finally, the northwest side of Great St. James (18º18.8'N, 64º49.9'W) was the only site that was characterized by a patch reef. This site was adjacent to (~20 m away) the rocky shoreline and Current Cut Passage, which experiences moderate to strong bidirectional tidal currents. The collectors at this site were suspended three meters below the surface in water that was approximately eight meters deep.

SAMPLING AND ANALYSIS

Collectors were sampled every two weeks over a 12 month period. Each collector was enclosed in a one millimeter mesh bag prior to being brought to the surface for inspection. All lobster pueruli and juveniles were counted and staged as follows: transparent, semi-pigmented, pigmented, and algal-phase juvenile, based on descriptions by Bannerot et al. (1992), CARICOM (1996), and Butler and Herrnkind (1997). Damaged, lost, or heavily encrusted collectors were replaced. Each sample represented a 14 to 16 day settlement period.

Catch per unit effort (CPUE) for each collector was calculated using:

CPUE = (total catch/number of days between sample periods).

CPUE calculations included first stage juveniles (dark pigmented body; ~5-15 mm CL) as well as pueruli. Samples that had missing or unattached collectors were not included in the data analysis. There was no difference in abundance between collectors at each site on each sample date (Paired-t: $p > 0.05$) in all cases except Cas Cay. Collectors at each site, except Cas Cay, were therefore combined in subsequent analysis. Collectors at Cas Cay often broke and were lost, leaving either single sample or no sample for this site over eight sample periods. Data were therefore log (x +1) transformed to conform to the assumptions of parametric testing. Following transformation, collectors tended to differ in total catch (ANOVA: $F_{1, 52} = 3.825$, $p = 0.056$). Therefore, comparisons between sites were made using a mean CPUE calculated for each site.

Timing in settlement was examined graphically by month and site. Spatial patterns in settlement were also investigated graphically and using standard one-way ANOVAs to test for differences in catch per unit effort between sites. Additionally, each sample date was classified into one of four lunar phases: new moon, first quarter, full moon and last quarter. Sample dates without a distinct/obvious lunar phase were assigned to the nearest lunar phase.

Comparison of CPUE between years was made graphically and using ANOVA to test for differences between years. CPUE in the previous studies by Quinn and Kojis (1997) and Kojis et al. (2003) were derived using a different method and were recalculated from the original data to allow direct comparison across years. Additionally, the NW Great St. James and SW Great

St. James sites in 2003 were combined to compare to the 1992 - 1993 and 1997 - 1998 data sets.

RESULTS

Five sites, with two Witham collectors each, were sampled from 18 June 2002 to 17 June 2003. A total of 202 postlarvae were observed (Table 1). Of the total catch, ten (5%) of the pueruli collected were transparent, 19 (9%) were semi-pigmented, 28 (14%) were pigmented, and 145 (72%) were early algal-phase juveniles (Table 1).

Table 1. Number of *Panulirus argus* postlarvae on Witham collectors of different stages settling at each site, 2002-2003. Numbers in brackets indicate the total number of samples per site.

Site	Transparent	Semi-pigmented	Pigmented	Juvenile	Total
Mangrove Lagoon (27)	0	1	0	18	19
Cas Cay (24)	0	4	0	14	18
Nazareth Bay (27)	8	10	25	84	127
NW, Great St. James (27)	1	3	0	6	10
SW, Great St. James (27)	1	1	3	23	28
Total (132)	10	19	28	145	202

Pueruli abundance was consistently low across most sites (Figure 2). However, overall pueruli abundance in Nazareth Bay was considerably higher than the other four sites (Figure 2) with 127 postlarvae counted during the study. The overall catch between the Mangrove Lagoon and Cas Cay sites was similar with 19 and 18 postlarval juveniles, respectively. NW Great St. James exhibited the lowest total catch with 10 postlarvae while SW Great St. James had a total catch of 28 (Table 1, Figure 2).

Catch per unit effort (CPUE) varied greatly across sample dates (Figure 3). Similarly, differences existed in the CPUE between sites (Mean $\pm$ S.D: Mangrove Lagoon: 0.03 $\pm$ .04, Cas Cay: 0.03 $\pm$ 0.05, Nazareth: 0.18 $\pm$ 0.35, NW St James: 0.01 $\pm$ 0.03, SW St James: 0.04 $\pm$ 0.07; One-way ANOVA: $F_{4, 127} = 4.355$, $p = 0.002$). Nazareth Bay consistently yielded a higher CPUE in 2002 - 2003 than the other four sites (Figure 3).

Peaks in settlement occurred primarily in the spring and early summer (Figure 4). The Mangrove Lagoon, Cas Cay, and NW Great St. James sites all had low settlement not exceeding 0.15 CPUE for any sample period. Seasonal peaks for these sites were in the spring (Figure 3). The SW Great St. James site had highest settlement during the summer months, with a peak CPUE of 0.32 (Figure 3). The greatest settlement occurred in May 2003 at the Nazareth Bay site, with a CPUE of 1.54 (Figure 3).

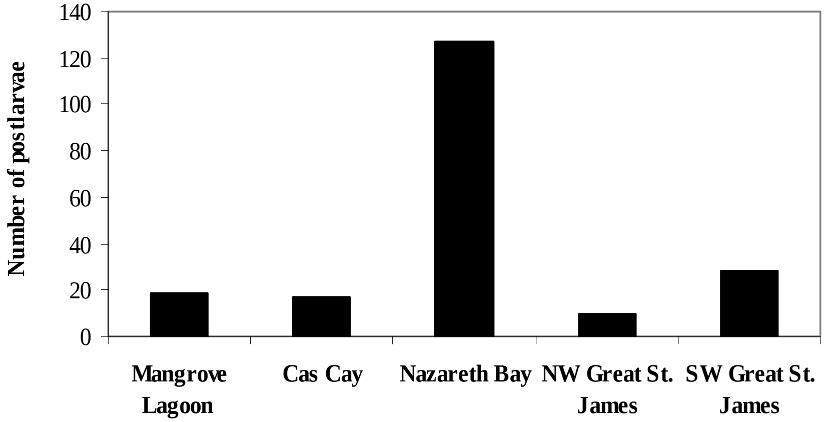

Figure 2. Total catch of *Panulirus argus* postlarvae on Witham collectors at each site in 2002 - 2003.

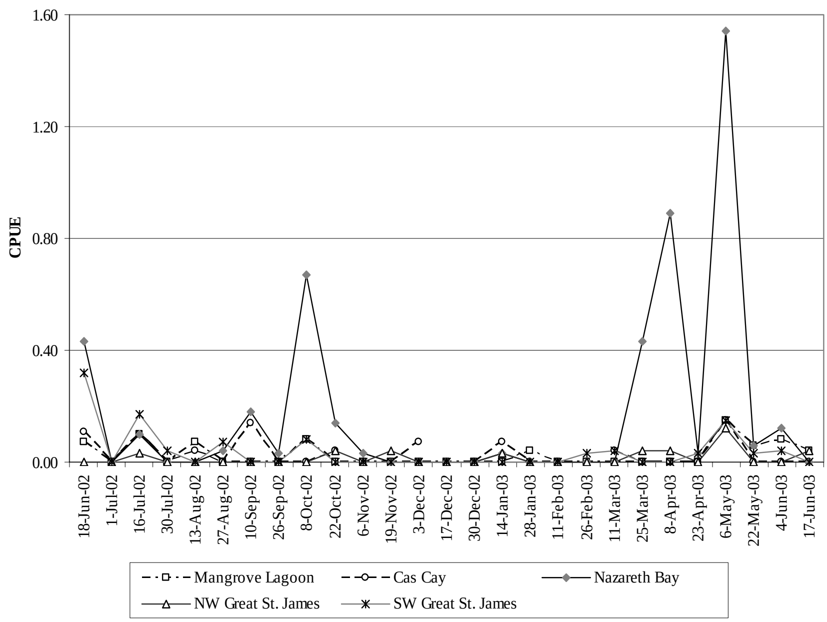

Figure 3. Mean catch per unit effort (pueruli/day) of postlarval *P. argus* for each sample date at all sites, 2002 - 2003.

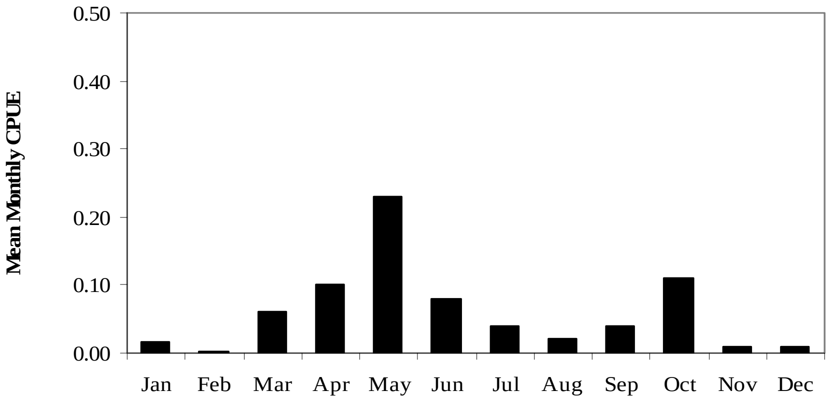

Figure 4. Seasonal variation in the mean monthly CPUE, all sites combined, 2002 - 2003.

Pueruli settlement was greatest for all sites during first quarter moon phases (Table 2). The total number of pueruli collected during the first quarter phase accounted for 73% of all settlement. CPUE was combined according to lunar phase for all sites. The greatest CPUE was during samples that were most closely associated with first quarter and new moon phases (0.09 and 0.10 respectively; Table 2).

Table 2. Number of postlarval spiny lobster collected on Witham collectors, 2002-2003, in relation to lunar phase (n = number of samples) and the combined mean CPUE ± SD for each lunar phase.

	Number of postlarvae			
Site	new moon (n = 2)	first quarter (n = 11)	full moon (n = 5)	last quarter (n = 9)
Mangrove Lagoon	2	15	1	1
Cas Cay	2	15	1	0
Nazareth Bay	16	91	5	15
NW, Great St. James	0	6	3	1
SW, Great St. James	2	21	0	5
Total	22	148	10	22
Combined CPUE	0.09± 0.21	0.10± 0.24	0.02± 0.03	0.02± 0.07

CPUE was generally greater in 1992 - 1993 than in either 1997 - 1998 or 2002 - 2003 (Two-way ANOVA: $F_{2, 280} = 10.88$, $p < 0.001$, Table 3). Similarly, across all years, the average CPUE differed between sites ($F_{3, 280} = 8.798$, $p < 0.001$) CPUE has steadily declined from 1992 to the present at both the Mangrove Lagoon site and the St. James site. From 1997 - 1998 to 2002 - 2003 CPUE declined at all sites except the St. James sites where the mean annual CPUE increased slightly from 0.02 to 0.03, respectively.

Table 3. Comparison of mean annual CPUE (Mean ± SD) by site and between years. *indicates data were not collected.

	Mean annual CPUE ± SD				
Year	Mangrove Lagoon	Cas Cay	Nazareth Bay	Great St. James	**Combined Mean Annual CPUE ± SD**
1992-1993	0.23 ± 0.30	*	*	0.16 ± 0.30	0.20 ± 0.29
1997-1998	0.09 ± 0.10	0.21 ± 0.31	0.30 ± 0.46	0.02 ± 0.04	0.15 ± 0.30
2002-2003	0.03 ± 0.04	0.03 ± 0.05	0.18 ± 0.35	0.03 ± 0.04	0.07 ± 0.19

DISCUSSION

Many factors may have contributed to the temporal and spatial variability in recruitment of *Panulirus argus*. For example, low CPUE values at the Mangrove Lagoon site in 2003 may be reflective of water quality issues (as discussed in Quinn and Kojis, 1997 and Kojis et al. 2003) and/or lack of suitable juvenile habitat. Acosta and Butler (1997) suggest that although mangrove habitats may be important nursery habitats the use of such is dependant on sheltering characteristics. Kojis et al. (2003) suggested that high CPUE values in the mangrove lagoon may have been a function of the site's proximity to pueruli settlement habitat. However, in 1999 hurricane Lenny disrupted the natural tidal flow at this site by piling coral rubble at the lagoon/ seaward interface. The resultant berm limited water flow into the lagoon and may have resulted in a reduction of suitable juvenile habitat as well as a reduction of larval supply to the site. A *Porites porites* bed used to lie near the Mangrove Lagoon site. However, hurricane Lenny devastated the *P. porites* bed (discussions with Division of Fish and Wildlife staff) and reduced water flow such that *P. porites* growth was probably limited. The *P. porites* bed, which at one time would have provided adequate juvenile habitat, has since been covered with sediment and algae. Postalgal spiny lobsters have been demonstrated to prefer silt-free environments with adequate amounts of stony corals, but make use of mangrove prop roots whenever coral cover is sparse (Herrnkind et al. 1988 in Acosta and Butler 1997). The decrease in CPUE in the mangrove lagoon before and after hurricane Lenny, suggests that although mangrove habitats may be important nursery areas, as implied by Little (1997), the absence of nearby coral for the postalgal juvenile stage may have a greater influence on postlarval settlement than merely the presence of mangroves.

Furthermore, Nazareth Bay which is close to a rock shoreline, consistently demonstrated high settlement rates over the years (see Table 3) despite the absence of mangroves. As discussed in Kojis et al. (2003) the current flow to this site may increase the supply of pueruli. Similarly, lower CPUE values at the St. James sites may be due to their orientation to the mass water flow; these sites appear to be oriented in the lee of an easterly current. Additionally, the NW St. James site is situated near an area that experiences heavy tidal currents which may flush pueruli past the collectors. Current flows may, therefore, act in tandem with water quality and juvenile habitat availability to create complex spatial patterns in pueruli settlement.

In this study, the timing of greatest settlement was in the spring/summer (April- June). These findings are consistent with Quinn and Kojis (1997) in which they report highest settlement during the summer months (April - October). It is suggested that the larval phase of lobster can exceed nine months (Butler et al. 1997; Acosta and Butler 1999), therefore it is likely that pueruli settlement in the U.S. Virgin Islands is dependant on an upstream supply.

In the Florida Keys, weekly collection of *P. argus* indicated that peak supply occurred during new moon and first quarter lunar phases (Acosta *et al.*, 1997). In the U.S. Virgin Islands, Quinn and Kojis (1997) report higher CPUE during new moons than full moons. The findings from this study are similar, however, in this study lunar cycles were broken into four lunar phases rather than two. The results of this study indicate that higher CPUE values occurred during first quarter new moon phases (Table 2). Pueruli typically travel and arrive at near-shore settlement areas during new moon and first quarter lunar phases to avoid predation (Heatwole et al. 1992). Therefore, settlement may be triggered by the dark periods of a new moon and carry through the first quarter phase, resulting in higher catches of pueruli during the first quarter as observed in this study.

Settlement has steadily declined from 1992 - 1993 at similar sites. Unfortunately, there are no clear reasons for the decline in pueruli settlement over the years. However, because of such a lengthy larval phase (Butler et al. 1997, Acosta and Butler 1999), pueruli supply is probably not local; therefore, it is unlikely that the decline in CPUE shown in this study is related to mortality or catch of adult *P. argus* in the U.S. Virgin Islands, but may be due in part to habitat degradation or water quality parameters.

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