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THE USE OF WITHAM COLLECTORS TO INCREASE PRODUCTION IN LOBSTER (*PANULIRUS ARGUS*) MARICULTURE

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ABSTRACT

The western Atlantic spiny lobster (*Panulirus argus*) is the largest and the most widely distributed Caribbean lobster. Because of the high consumer demand and high price consumer's are willing to pay for lobster, scientists are exploring ways to raise lobsters in captivity. One approach to producing lobsters is full scale mariculture where lobsters are raised throughout their entire life cycle in captivity. Although researchers have successfully mated and spawned spiny lobsters in captivity, they have found it difficult to rear the larvae because of their long and complex larval life. Another approach is to collect the first lobster settlement stage, the puerulus, from the wild. The transparent pueruli settle in shallow water natural habitats such as mangroves and on artificial habitats, called Witham collectors. In the U.S. Virgin Islands pueruli settlement occurs all year round with seasonal settlement peaks. The collection of pueruli is a cheaper, easier, and faster technique to establish a lobster mariculture operation than developing and maintaining a breeding stock and raising larvae to settlement stage. Interest in lobster mariculture is likely to continue to increase as the human population increases and as diet-conscious people increase their sea food consumption. Maximum sustainable yields for lobster fishing in many islands have already been exceeded and more effort is being spent on techniques to make lobster mariculture profitable.

INTRODUCTION

The world's population consumed 62% of the estimated maximum sustainable yield for finfish in 1978. United Nations fisheries scientists estimated that by 1985 the world demand for finfish would exceed the maximum world supply in all major fisheries (Van Olst, 1980). It is now 1994 and major fisheries on the northeast coast of the USA have declined precipitously and drastic action--the complete closing of a major fishery and at least the temporary loss of thousands of jobs--has occurred. This is not the first fishery that has collapsed, nor will it be the last.

The western Atlantic spiny lobster, *Panulirus argus*, supports a small commercial/recreational fishery in the U.S. Virgin Islands. USVI catches from 1980-1988 were fairly stable at 19 tons (NOAA, 1992), but appear to have declined since the 1960s (Swingle, *et al.*, 1969). Despite the recent total catch stability, inshore stocks of lobsters have been depleted and fishermen must travel further offshore, spending more time and exerting more effort to catch lobster. Of course, the high price of lobster still makes lobster fishing profitable. Whole lobster sells from about $5-6.00 per lb locally. Frozen tails cost up to $21.00 per lb.

The high price of lobster and high consumer demand make the spiny lobster a potential candidate for mariculture. Spiny lobsters also have other characteristics that make them amenable to commercial cultivation. These include their communal nature, lack of aggressive or cannibalistic behavior, and the wide variety of food that they will accept (Ingle, 1979). *Panulirus argus* also has a fast growth rate if maintained at temperatures between 27 and 30°C. Lellis (1991) grew *P. argus* to market size in 16 months.

Although researchers have successfully mated and spawned spiny lobsters in captivity, they have found it difficult to rear the larvae, perhaps because of their long and complex larval development. The oceanic phyllosoma larvae of *Panulirus argus* metamorphose after an estimated at 6-9 months (Ingle *et al.*, 1963) into transparent nocturnally active pueruli which swim to inshore nursery areas aided by physical transport mechanisms (Lyons, 1980; Calinski and Lyons, 1983). There are 11 phyllosome larval stages, followed by a puerulus stage (Lewis, 1951). The pueruli settle selectively among structurally complex benthic vegetation, particularly the common benthic algae, *Laurencia* spp. (Marx and Herrnkind, 1985; Herrnkind and Butler, 1986; Marx, 1986; Butler and Herrnkind, 1991), among mangrove roots, on dock pilings, and boat bottoms. Settled pueruli metamorphose into first benthic instars (Sweat, 1968) 5-7 mm in carapace length. Unfortunately, the complex biological requirements of culturing phyllosome lobsters make this task more difficult than the domestication and rearing of terrestrial animals such as poultry and livestock.

Pueruli are often seen in large numbers in shallow water habitats and it has been suggested that it may be possible, if recruitment of pueruli is in excess of natural population requirements, to capture sufficient numbers of puerulus stage lobsters for aquaculture. Collecting pueruli in the wild as they drift inshore would eliminate the need to establish costly larval rearing facilities. This approach was first suggested over 25 years ago (Ingle and Witham, 1968; Chittleborough, 1974; Serfling and Ford, 1975). The transparent pueruli settle readily on artificial habitats, called Witham collectors. These collectors have been found to be a good relative measure of the number of pueruli in an area (Witham *et al.*, 1968) and have been used to make general comparisons of puerulus abundance among regions (Little and Milano, 1980).

This study focussed on the spatial and temporal variability of pueruli settlement and examined the potential for using pueruli in lobster mariculture. We asked the following questions:

1. Does the recruitment rate of pueruli vary with habitat?
2. Are there seasonal settlement patterns?
3. Is there variation in settlement associated with lunar phase?
4. Does settlement vary between years?
5. Is there regional variation in the settlement rate in the Caribbean?

MATERIALS AND METHODS

Biological Sampling

Lobster pueruli were collected using modified Witham collectors. The collectors consist of six pieces of plastic coated "hogshair" air conditioning filters each 45cm x 55cm, for a total of 1.5m^2 of surface area. The filters are supported by a PVC frame. The capital cost for a single collector is about $40. This could be reduced if used air conditioning filters were used. The filters need to be replaced when they began to disintegrate. The replacement frequency in this study was between 3 - 6 months after immersion. Settlement on replacementcollectors was comparable with the settlement on collectors that had been deployed for several months.

Three sites on the south side of St. Thomas were chosen for study: the Mangrove Lagoon, Saba Island and Great St. James Island (Fig. 1a). In June 1992, three modified Witham collectors were placed in Mangrove Lagoon (Fig. 1b). The collectors were deployed at a depth of 1 m in water 2 m deep over a substrate of fine sand and mud. The mangrove community was dominated by the red mangrove, *Rhizophora mangal* (Nichols and Towle, 1977). In July 1992, two additional collectors were deployed in waters off Saba Island 3 km offshore of the southwest end of St. Thomas. The collectors were moored 3 m from the surface in water 8 m deep. They were positioned between a manatee/turtle grass (*Syringodium filiforme*/*Thalassia testudinum*) sea grass meadow and a *Montastraea annularis*/*Millepora* sp. dominated reef. A further two collectors were deployed off Great St. James on the southeast end of St. Thomas at a similar depth with similar features.

The Witham collectors were sampled approximately fortnightly by placing a 2 mm mesh bag around each collector and inspecting each collector on board a 21 foot open boat. All pueruli were removed from collectors, counted, and staged, and then collectors were returned to the water. Each sample represented recruitment to the collector over a 10 to 15 day period. When considering lunar effects, the phase before or on the sampling date was used.

The measure of catch per unit effort (CPUE) was determined by dividing the number of pueruli counted by the number of collectors at the site and further standardizing for the number of days between collections.

Hydrological Sampling

Subsurface sea water temperature was recorded hourly to the nearest 0.05°C at the location of one of the collectors off Saba Island from 28 March 1992 to 30 March 1994 using a Hugrun Seamon s/f brand underwater temperature recorder (UTR).

RESULTS

In 16 months of sampling, 36 transparent, 53 semi-pigmented and 331 pigmented post larvae, totaling 420 pueruli or post-larval lobsters (Fig. 2), were collected in a total of 227 samples (one sample refers to one Witham collector sampled at a single sampling time). Settlement of at least one individual was observed in 77% of the samples.

Three treatments (lunar phase, site, and month) were considered in an Analysis of Variance test of catch data (Table 1). Catches were very highly significantly affected by site location, month, and interaction of site and lunar phase. Lunar phase was not a significant influence when all the sites were pooled.

Seasonal Variation

Although settlement occurred throughout the year, the settlement rate from April to October, the summer months, was 2.8 times greater than from November to March, the winter months (Fig. 3).

Lunar Variation

It has been suggested that pueruli settle primarily during the new moon phase. However, only at Saba Island was settlement statistically significant with respect to lunar phase (*t*-test, N=16, $P<0.022$). At this site, settlement around new moon was over six times greater than during full moon. During new moon phase, catches at Saba Island ranged from 0 to 6.5 CPUE per collector while during the full moon phase catches ranged from 0 to 2.0 CPUE (Table 2). Only once were catches greater during a full moon period than during either of the juxtaposed new moon collections.

Settlement was greater at new moon at Great St. James and the Mangrove Lagoon (Table 2), but the results were not statistically significant.

Annual Variation

There has been an overall decline in CPUE between years in the Great St James and Saba sites (Fig. 4). Settlement in 1993 at Great St. James and Saba was only 14% and 11% of 1992 settlement, respectively. However, settlement within the Mangrove Lagoon estuary was 41% greater in 1993 than in 1992. These inter-annual variations probably reflect the natural variability of lobster settlement which is influenced by currents and tidal flow, among other factors.

Spatial Variation

Large significant differences in the number of post larvae settling existed between sites (Fig. 5). Settlement was highest on the two collectors at the entrance to the Mangrove Lagoon with a CPUE (catch per unit effort) of 6.04 pueruli. Pueruli were present on 72% of the sampled dates at that site. The next highest settlement rate was on collectors located at Great St. James Island. This site had a CPUE of 2.29 puerulus and puerulus were caught in 70% of the samples. The off-shore island, Saba, had a CPUE of 1.03 and pueruli were present on 45% of the sampling dates. The collector located furthest inside the Mangrove Lagoon estuary had the lowest settlement rate (0.55 CPUE) with pueruli settling on only 38% of samples. Witham collectors are considered less effective within estuaries since they must compete with natural habitat suitable for pueruli settlement.

The Great St. James site, with the second highest lobster recruitment, is adjacent to Current Cut which experiences water movement up to 50 cm/sec. Currents along with wind-induced surface water movement probably enhancesettlement at this site. The Saba Island site which is furthest away from an estuary receives a near constant easterly current, but experienced the least settlement with a settlement rate of only 17% of the settlement rate in the estuary.

Sea water temperature

The sea water temperature range was 4.45°C. The highest temperature recorded was 29.6°C in October 1992 and lowest 25.15°C in January 1993 (Fig. 6) (Quinn and Kojis, 1994). The CPUE was not significantly correlated with water temperature ($r = 0.26$, $N = 16$).

DISCUSSION

The potential for commercial success of a lobster mariculture project is enhanced by collecting the greatest number of puerulus with the least effort. Consequently, knowledge of the optimal location and time for collection is essential.

Temporal Variation

Pueruli settlement was seasonally variable with the greatest settlement occurring in the 6 months from April to October. However, during the summer months fewer pueruli settled when the wind speed decreased to less than 5 knots for over two weeks.

It has been suggested that recruitment rates may be related to temperature. In Bermuda, Ward (1989) reported that most settlement occurred in late summer with virtually no mid-winter recruitment. Ward suggested that the cooler oceanic water around Bermuda (32°N) in winter may act to inhibit the metamorphosis of the phyllosoma to the puerulus stage and suggested that 24°C might be the lower limit.

In St. Thomas, water temperatures do not fall below 25.1°C and average monthly temperatures are between 26 and 29°C (Fig. 6). Although some settlement occurred throughout the year, the period of lowest recruitment from November to March coincided with the period of lowest temperatures and this tends to support Ward's hypothesis. However, settlement of pueruli occurs mainly from February to May in Florida which spans winter and spring months and suggests that low temperatures do not necessarily inhibit larval metamorphosis.

Time of spawning may also be a factor influencing pueruli availability. Year round spawning of *Panulirus argus* was recorded for the neighboring island of Puerto Rico (Mattox, 1956). However, no data were available on the annual variation in spawning intensity in Puerto Rico.

With any renewable natural resource the knowledge of various parameters such as mortality, fecundity, recruitment, and habitat preference can be used topredict population sizes and thereby regulate harvest and protect nurseries. However, studies of recruitment of *Panuluris argus* are difficult owing to the long (6-9 month) pelagic larval stage. The specific sources of the phyllosoma larvae and pueruli to Virgin Islands stocks, each source's contribution to the stocks, an accurate determination of the length of time the larvae spend in the plankton, the growth rates of the larvae, and the conditions relating to their movement to inshore waters are still unknown.

Spatial Variation

Although collectors at the entrance to the Mangrove Lagoon estuary had the highest CPUE, the estuary is not a pristine habitat. Over one half million gallons per day of minimally treated effluent from four sewage treatment plants are discharged directly into the mangrove lagoon or its water shed. The effluent is discharged down current from the collectors throughout most of the year. However, when the trade winds die and the wave induced flushing ceases, especially for extended periods as occurs commonly in September and October (Mortenson, n.d.), the lagoon water becomes green and visibility decreases to less than 0.3 m. The Witham collector furthest in the estuary had the lowest CPUE. However, Witham collectors are considered less effective within estuaries because they compete with natural settlement areas. Further study is necessary to determine if the poorer water quality inside the estuary contributed to the lower settlement rate on this collector.

The Great St. James site, with the second highest level of lobster recruitment, is adjacent to Current Cut which experiences water movement up to 0.5 m/sec^{-1} compared with 0.1-0.2 m/sec^{-1} at other sites. Currents along with wind-induced surface water movement probably enhance settlement. The site furthest away from an estuary at in the leeward side of Saba Island receives a nearly constant easterly current, but experienced the least settlement with settlement rates 17% of those in the estuary.

Regional Variation

Settlement is variable not only within an island group, but between island groups. For example, in Antigua, the highest settlement rate was on the five collectors in locations that receive direct exposure to the southeast trade winds and eastwardly flowing equatorial current (Anon., n.d.). However, not all sites on that side were highly productive. It is unclear what effect currents, eddies or other types of micro-environment have in concentrating pueruli.

In southern Florida collectors deployed in channels had less settlement than collectors in slower moving water juxtaposed to channels (Little, 1977). In Bermuda, the greatest settlement occurred on collectors adjacent to major channels that pass a large volume of water. Ward (1989) observed that some water movement will increase settlement, but there may be a flow rate, which when exceeded, results in reduced settlement.

The high CPUE in the outer Mangrove Lagoon collectors in St. Thomas compares favorably with the observation by Little (1977) in Florida that postlarvae were more abundant in collectors placed in mangroves than in collectors placed in deeper channels. Little (1977) interpreted this to suggest the importance of the near-shore environment as juvenile nursery areas and this study supports his contention.

Along with differences in preferred settlement locations between different areas, settlement rates vary between island groups. Simultaneous pueruli settlement rates were obtained from August 1987 through July 1988 in Antigua, Florida Keys, and Bermuda (Hunt, *et al.*, 1990). The mean catch per collector (CPUE) ranged from 9.3 puerulus in Antigua, 6.1 in Florida Keys and 1.4 in Bermuda (Table 3). The CPUE for the Mangrove Lagoon, 6.04 puerulus, was comparable with settlement rates from the Florida Keys, but was 35% lower than that reported in Antigua. The off-shore site at Saba Island had a CPUE 1.03 that was comparable to the CPUE obtained in the off-shore waters around Bermuda (Fig. 7).

Another Antigua study (Anon. n.d.) with 35 collectors lasted 4 1/2 months. Settlement exceeded values obtained in this study in only two months, September and October in Antigua. The settlement in Antigua was 26% greater than this study in September 1992 (Antigua: 3.5 lobsters per collector (lpc), V.I. 2.8 lpc) and nearly 5 times greater than in October 1992 (Antigua: 6.3 lpc, V.I. 1.3 lpc). Another study in Antigua (Peacock, 1974) found settlement much higher in May and October.

Implications for Mariculture

According to van Olst *et al.* (1980), the essential characteristics that make an organism amenable to commercial aquaculture include:

1) an adequate consumer demand and profit potential for the species,
2) high food conversion efficiency,
3) resistance to disease,
4) the ability to reproduce in captivity, and
5) simple larval development

As mentioned earlier, there is a high consumer demand and consumers pay a high price for lobster. Also studies have shown that high water temperatures decrease grow out time and increase food conversion efficiency considerably. Water temperature in the Virgin Islands hovers around the ideal grow out temperature of 27 to 29°C. Most lobsters have proved to be hardy and the spiny lobster is probably resistant to disease although this needs to be studied. The only characteristic that is not met by this species is simple larval development. The length of larval development makes larval rearing costly and, at this stage, difficult.

The use of Witham collectors in regions with high puerulus abundances could increase the success of mariculture operations by eliminating the necessity to raise larvae. Clearly it would be cheaper and easier to use lobster pueruli from natural populations to establish a lobster mariculture operation than developing and maintaining a breeding stock and raising larvae for 6 to 9months. While this study used small experimental collectors, a commercial operation would probably deploy more and larger collectors.

Our study showed that Witham collectors can be used in the Virgin Islands to collect lobster pueruli and that to minimize time and effort of collection it is important to consider the site where collectors are placed. For example, areas near mangroves have the highest recruitment rates. Sites near reasonably strong currents also have high recruitment. Recruitment is seasonal with the spring and summer months having the highest recruitment rates. Lunar phase did not appear to be important with no statistically significant difference in the lunar time of settlement for the two sites with the highest recruitment rates.

Pueruli collection is, however, still fishing. The very long duration of larval stages presents problems in determining the source of recruits and the probable location of spawning population (Richards and Potthoff, 1981). There are no reliable regional estimates regarding what percentage of the puerulis survive to adults. Consequently, the effects on the natural population of collecting hundreds of pueruli cannot be assessed. It is, however, likely that natural mortality is high and that in a well-run mariculture system mortality is likely to be less.

If commercial mariculture of lobsters is successful, producers will need to convince permitting agencies that capture and removal of puerulus will not affect natural lobster populations. Studies of year-to-year fluctuation in the magnitude of *Panulirus* puerulus recruitment have been done in Florida (Herrnkind and Butler, 1986; Herrnkind *et al.*, 1988; Hunt *et al.*, 1990), Bermuda (Ward, 1989; Farmer, *et al.*, 1989), Antigua (Peacock, 1974), and with another species of *Panulirus* in Hawaii (MacDonald, 1986). Settlement variability implicates puerulus recruitment levels as a possible factor regulating harvestable stock abundance. Therefore, monitoring of the effect of puerulus collection on natural populations is important. The question is how to do this. The contribution of local reproductive stock to recruitment in any given area is unknown, but it is likely that most of the larvae are transported hundreds of kilometers before they settle (Phillips and McWilliam, 1986).

Careful records of puerulus CPUE by mariculture operators will help to determine the effect of puerulus "fishing", especially if lobster mariculture becomes widespread in the Caribbean. It will also be important to ensure accurate reporting of catch and effort in the local lobster fishery.

Additionally, producers would also need to consider releasing a percentage of grow out stock, especially females, to replenish the stocks. As most pueruli in a given area are considered to have originated from up current (Lyons, 1981; Menzies and Kerrigan, 1979) the replacement of pueruli with older lobsters is more likely to aid fisheries down current than local fisheries in the short term. Survival of these farm-raised females in the wild will need to be monitored.

Interest in lobster mariculture is likely to continue to increase as the human population increases and as diet-conscious people increase seafood consumption. Maximum sustainable yields for lobster fishing on many islandshave already been exceeded. Lobster mariculture may be a method of relieving pressure on natural populations while meeting consumer demand.

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REFERENCES

Anon., n.d. Report to Antigua / Barbuda Government on spiny lobster. pp.1-40.

Butler, M.J. IV and Herrnkind, W.F. 1991. Effect of benthic micro habitat cues on the metamorphosis of pueruli of the spiny lobster *Panulirus argus*. Journal of Crustacean Biology. 11(1):23-28.

Calinski, M.D. and Lyons, W.G. 1983. Swimming behavior of the puerulus of the spiny lobster *Panulirus argus* (Latreille, 1804) (Crustacea: Palinuridae) Journal of Crustacean Biology. 3(3):239-335.

Chittleborough, R.G. 1974. Western rock lobster reared to maturity. Aust. J. Mar. Freshwater Res. 25:221-225.

Farmer, M.W., Ward, J.A. and Luckhurst, B.E. 1989. Development of spiny lobster (*Panulirus argus*) phyllosoma larvae in the plankton near Bermuda. Proceedings of the 39th Gulf and Caribbean Fisheries Institute. 39:289-301.

Herrnkind, W.F. and Butler, M.J. 1986. Factors regulating pueruli settlement and juvenile micro habitat pueruli settlement and juvenile micro habitat use by spiny lobsters, *Panulirus argus*. Mar. Ecol. Prog. Ser. 34:23-30.

Herrnkind, W.F., Butler, M.J. and Tankersley, R.A. 1988. The effects of siltation on recruitment of spiny lobsters, *Panulirus argus*. Fisheries Bulletin, United States. 86:331-338.

Hunt, J., Bannerot, S.P. Ward, J. and Matthews T.R. 1990. Comparison of *Panulirus argus* puerulus influx between three western Atlantic locations: Antigua, Bermuda and Florida, USA. Program/ Abstracts International Workshop on Lobster Ecology and Fisheries, p.25.

Ingle, R.M., Eldred, B. Sims, H.W. and Eldred, E.A. 1963. On the possible Caribbean origin of Florida's spiny lobster populations. Tech. Ser. Fla. Board Conserv. 40:1-12.

Ingle, R.M. and Witham, R. 1968. Biological considerations in spiny lobster culture. Gulf Carib. Fish. Inst., Univ. Miami, Proc. 21:158-162.

Ingle, J.M. 1979. Ecology and growth of juvenile California spiny lobster, *Panulirus interruptus* (Randall). Ph.D. Dissertation. University Southern California, Sea Grant Dissertation Service, USCSG-TD-03-79.

Lellis, W.A. 1991. Spiny lobster, a mariculture candidate for the Caribbean? World Aquaculture. 22(1):60-63.

Lewis, J.B. 1951. The phyllosoma larvae of the spiny lobster *Panulirus argus*. Bull. Mar. Sci. Gulf Caribb. 1(2):89-103.

Little, Jr., E.J. 1977. Observations on recruitment of post larval spiny lobsters, *Panulirus argus*, to the South Florida coast. Florida Marine Research Publications. 29:1-35.

Little, E.J. Jr. and Milano, G.R. 1980. Techniques to monitor recruitment of post larval spiny lobsters, *Panulirus argus*, to the Florida Keys. Fla. Mar. Res. Publ. 37:1-16.

Lyons, W.G. 1980. The post larval stage of scyllaridean lobsters. Fisheries. 5(4):47-49.

Lyons, W.G. 1981. Possible sources of Florida's spiny lobster population. Proceedings of the 33th Gulf and Caribbean Fisheries Institute. 33:253-266.

MacDonald, C.D. 1986. Recruitment of the puerulus of the spiny lobster, *Panulirus marginatus*, in Hawaii. Can. J. Fish. Aquat. Sci. 43:2118-2125.

Mattox, N.T. 1956. A preliminary report on the biology and economics of the spiny lobster in Puerto Rico. Proc. Gulf Carib. Fish. Inst. 8:69-70.

Marx, J.M. 1986. Settlement of spiny lobster, *Panulirus argus*, pueruli in south Florida: an evaluation from two perspectives. Can. J. Fish. Aquat. Sci. 43:2221-2227.

Marx, J.M. and Herrnkind, W.F. 1985. Macroalgae (Rhodophyta: *Laurencia* spp.) as habitat for young juvenile spiny lobsters, *Panulirus argus*. Bull. Mar. Sci. 36(4):423-431.

Menzies, R.A. and Kerrigan, J.M. 1979. Implications of spiny lobster recruitment patterns of the Caribbean - a biochemical genetic approach. Proceedings of the 31th Gulf and Caribbean Fisheries Institute. 31:164-178.

Mortenson, B. n.d. Hydrological survey of the Mangrove Lagoon. unpublished manuscript. pp.18.

National Oceanic and Atmospheric Administration. 1992. Our living oceans. Report on the status of U.S. living marine resources, 1992. NOAA Tech. Memo. NMFS-F/SPO-2. pp.150.

Nichols, M. and Towle, E. 1977. Water, sediments and ecology of the Mangrove Lagoon and Benner Bay, St. Thomas. Island Resource Foundation. Tech. Report. 1:1-159.

Peacock, N.A. 1974. A study of the spiny lobster fishery of Antigua and Barbuda. Proceedings of the 26th Annual Meeting Gulf and Caribbean Fisheries Institute. 26:117-130.

Phillips, B.F. and McWilliam, P.S. 1986. The pelagic phase of spiny lobster development. Can. J. Fish. Aquatic. Sci. 43:2153-2163.

Quinn, N.J. and Kojis, B.L. 1994. Monitoring sea water temperatures adjacent to shallow benthic communities in the Caribbean Sea: A comparison of AVHRR satellite records and *in situ* subsurface observations. Marine Technology Journal. 6:28-35.

Richards, W.J. and Potthoff, T. 1981. Distribution and seasonal occurrence of larval pelagic stages of spiny lobsters (Palinuridae, *Panulirus*) in the western tropical Atlantic. Proceedings of the 33th Annual Meeting Gulf and Caribbean Fisheries Institute. 33:244-252.

Serfling, S.A. and Ford, R.F. 1975. Laboratory culture of juvenile stages of the California spiny lobster, *Panulirus interruptus* (Randall), at elevated temperatures. Aquaculture. 6:377-387.

Sweat, D.E. 1968. Growth and tagging studies on *Panulirus argus* (Latreille) in the Florida Keys. Florida Board of Conservation Marine Research Laboratory Technical Series. 57:1-30.

Swingle, W.E., Dammann, A.E. and Yntema, J.A. 1969. Survey of the commercial fishery of the Virgin Islands of the United States. Proceeding of the 22nd Annual Session, Gulf and Caribbean Fisheries Institute. 26:110-121.

van Olst, J.C., Carlberg, J.M. and Hughes, J.T. 1980. Aquaculture. in: J.S. Cobb and B.F. Phillips, eds., The biology and management of lobsters. Vol. 2, pp. 333-384. Academic Press, New York, New York.

Ward, J. 1989. Patterns of settlement of spiny lobster (*Panulirus argus*) Post larvae at Bermuda. Proceedings of the 39th Gulf and Caribbean Fisheries Institute. 39:255-264.

Witham, R., Ingle, R.M. and Joyce, Jr., E.A. 1968. Physiological and ecological studies of *Panulirus argus* from the St. Lucie estuary. Fla. Board Cons. Mar. Res. Lab. Tech. Ser. 53:1-31.

Table 1: ANOVA Between Lunar phase, site and month.

SOURCE	DF	SS	MS	F	P
MOON(A)	1	2.17	2.17	0.21	0.6519
MONTH(B)	14	708.55	50.61	4.83	0.0002
SITE (C)	2	291.35	145.67	13.91	0.0001
A*B	2	95.35	47.67	4.55	0.0194
A*C	28	1079.98	38.57	3.68	0.0005
A*B	14	96.15	6.86	0.66	0.7955
A*B*C	28	293.311	10.47		
TOTAL	89	2566.89			
GRAND AVG.	1	1521.11			

Table 2: Lunar cycle variation on catch per unit effort.

	TOTAL #PUERULI	TOTAL #PUERULI	1TRIP MAZ.	1 TRIP MAX.
SITE	FULL MOON	NEW MOON	FULL MOON	NEW MOON
GT ST. JAMES	31	56	17	33
SABA	0	25	0	13
MANGROVE	15	28	8	12

Table 3: Catch per unit effort of puerulus at various latitudes in the Caribbean Sea.

ISLANDS	LATITUDE	NUMBER OF COLLECTORS	MAX. CATCH	PEAK MONTH	MEAN CPUE	SITE
ANTIGUA	17°N	28	355	Feb/May Aug.	9.3	
USVI	18°N	7	29	August	6.04	Mangrove Reef
					2.29	St.James
					1.03	Saba
					9.55	Mangrove Inside
FLORIDA KEYS	25°N	3	61	August	6.1	
BERMUDA	32°N	10	44	March	1.4	

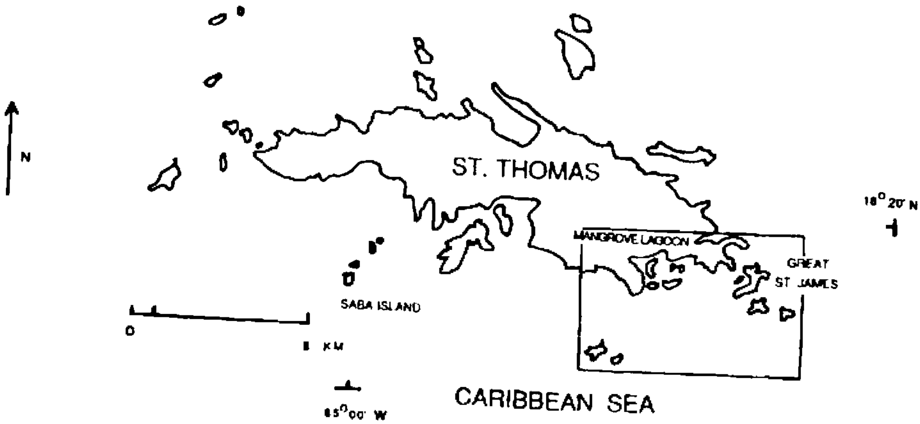

Fig. 1a: St. Thomas, U.S. Virgin Islands.

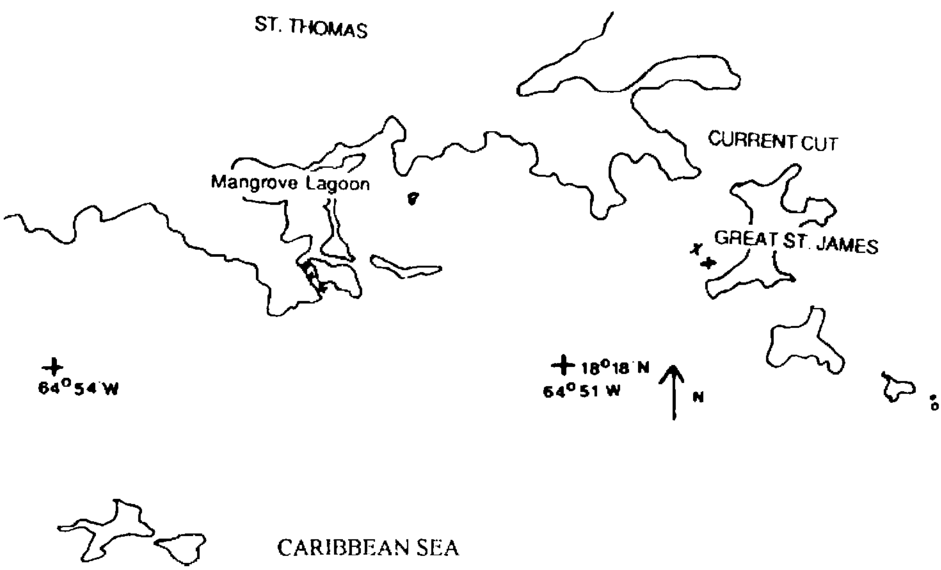

Fig. 1b: Eastern end of St. Thomas. Puerulus collector sites indicated by x.

WITHAM COLLECTOR DATA

LOBSTER PUERULUS

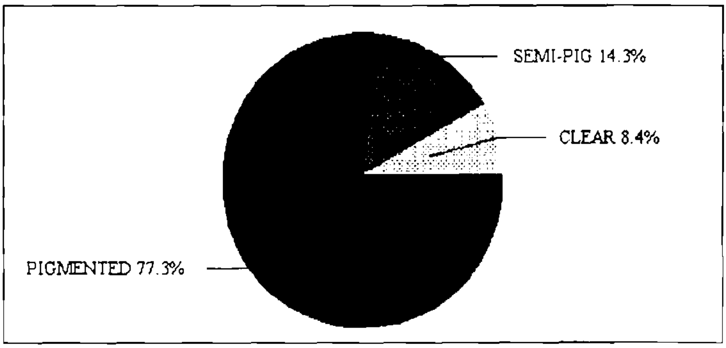

Fig. 2. Percentage of each puerulus stage for all sites.

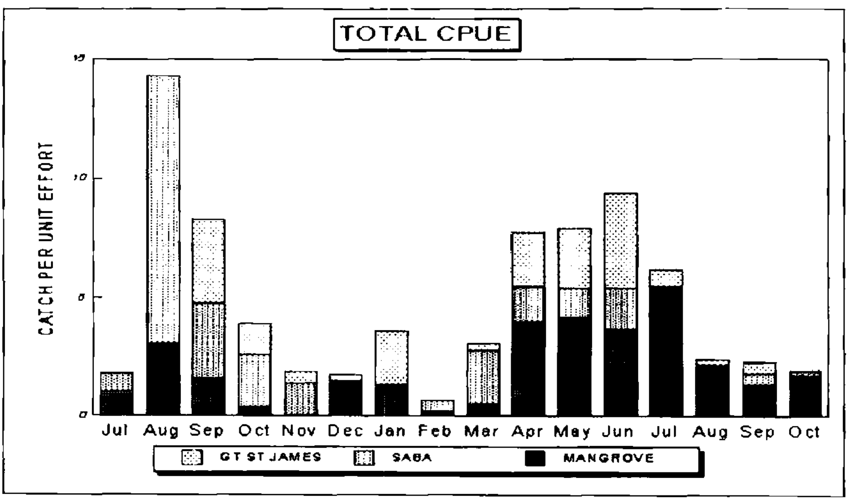

Figure 3. Monthly variation in catch per unit effort (CPUE) by site

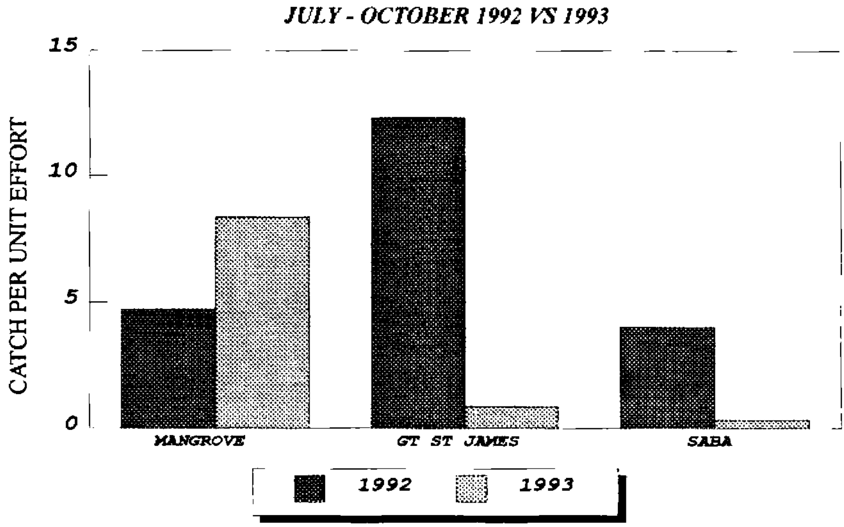

Fig. 4. Variation in catch per unit effort by year.

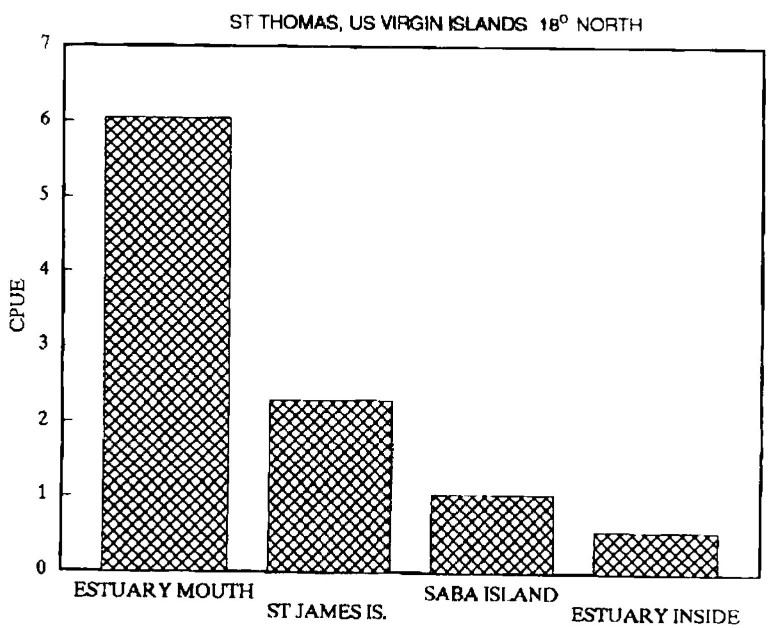

Fig. 5. Variation in catch per unit effort by site.

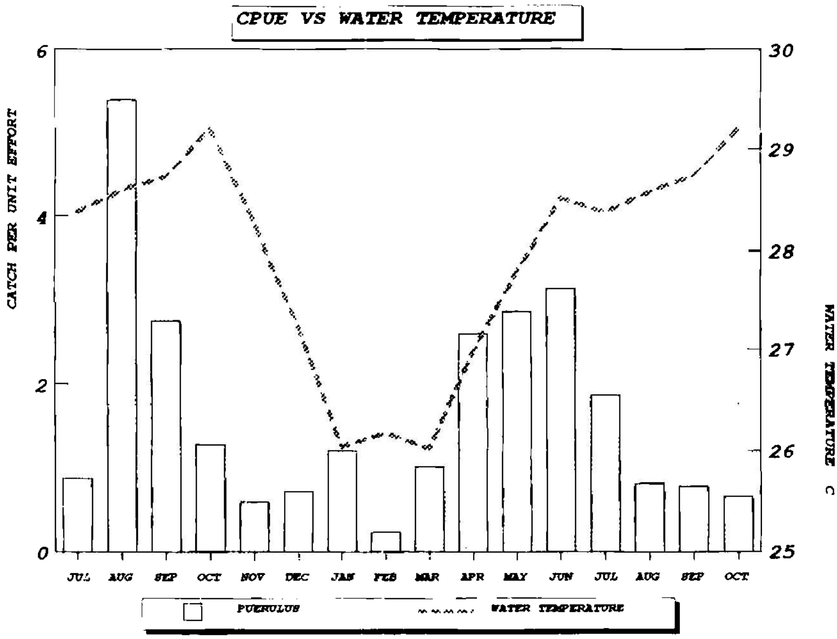

Fig. 6. Monthly total catch per unit effort and mean monthly subsurface sea water temperature.

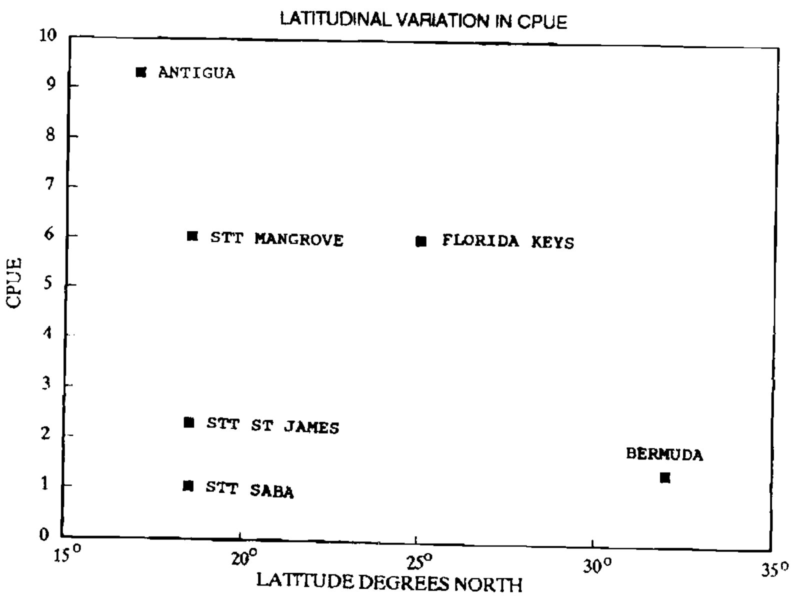

Fig. 7. Catch per unit effort in Antigua, Bermuda, Florida and St. Thomas.