Annual Juvenile Recruitment of Spiny Lobsters, Panulirus Argus (Decapoda, Palinuridae), in a Shallow Seagrass Bed and a Deeper Hard Bottom off Western Puerto Rico

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ANNUAL JUVENILE RECRUITMENT OF SPINY LOBSTERS, *PANULIRUS ARGUS* (DECAPODA, PALINURIDAE), IN A SHALLOW SEAGRASS BED AND A DEEPER HARD BOTTOM OFF WESTERN PUERTO RICO

BY

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ABSTRACT

We found 158 juvenile Caribbean spiny lobsters (*Panulirus argus*) recruiting over a year into 10 artificial shelters in shallow (2-3 m) seagrass beds, but none recruiting into 10 shelters on deeper (approximately 10 m) hard bottom. Spiny lobster juveniles were observed at 10 m or greater depth in submerged fish cages. They may have been strained out by currents rather than naturally recruiting. A large number of these cages inshore could impede natural lobster recruitment. One of the shallow shelters recruited most (85/158) of the juveniles and two shelters recruited most of all (118/158). With no discernable natural habitat difference, we assume that early recruitment into those shelters and the "guide effect" may have been responsible for these preferences. Previous Caribbean studies found the maximum settling periods of juveniles in August to December. Our results were similar with the exception of having more recruits one month later (August to January). Shelters with covers had more juveniles than those without covers; however, this result was largely due to the preponderance of juveniles in one shelter.

RESUMEN

Encontramos 158 juveniles de la langosta (*Panulirus argus*) que reclutaron en un periodo de un año en refugios artificiales en áreas llanas (2-3 m) de hierbas marinas, pero ninguno reclutó en los refugios artificiales de mayor profundidad (approx. 10 m) de sustrato duro. Se observaron juveniles a 10 m o más de profundidad en jaulas de acuacultura oceánica. Es posible que esto fuera por un efecto de filtración por las corrientes en lugar de reclutamiento natural. Colocar muchas de estas jaulas podría afectar el reclutamiento natural de la langosta. Uno de los 10 refugios artificiales reclutó a la mayor parte (85/158) de los juveniles y dos de los refugios reclutaron casi todas (118/158) las etapas de langosta observadas. En ausencia de una diferencia natural discernible de hábitat, asumimos que el reclutamiento temprano en esos refugios y el efecto guía "guide effect" puede haber sido responsable de esta preferencia. Estudios anteriores en el Caribe encontraron que el periodo de reclutamiento de

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juveniles era de agosto a diciembre. Nuestros resultados fueron semejantes a excepción de tener más reclutas un mes posterior (agosto a enero). Los refugios con coberturas mostraron más juveniles que ésos sin coberturas; sin embargo, este resultado fue en gran parte debido a la preponderancia de juveniles en uno de los refugios.

INTRODUCTION

The Caribbean spiny lobster (hearafter referred to as "lobster"), *Panulirus argus* (Latreille, 1804) (Decapoda, Palinuridae) is one of the most important fisheries in Puerto Rico, the Caribbean, and Florida (U.S.A.) (Holthuis, 1991; Baisre & Cruz, 1994; Ehrhardt, 1994; FAO, 2000). Morris et al. (1994) and SEDAR (2005) detailed the history of the lobster fisheries of the U.S. Caribbean. This fishery has been assessed six times since 1990 and found to be overfished (SEDAR, 2005). Mateo (2004) believes that overfishing is due to three factors: management failure to enforce size regulations, a lack of basic biological and ecological knowledge of lobster, and a lack of management oriented research.

Lobster juveniles are thought to recruit in shallow waters (Lipcius & Cobb, 1994). Therefore, most recruitment studies have been conducted in the shallows. Post larvae recruit at 10 m or deeper on commercial fish pen nets in Puerto Rico (Davis et al., 2007; E. H. Williams, unpubl. data). The present study was conducted, in part, to compare recruitment in the shallows (2-3 m) vs. at greater depth (approx. 10 m). Juvenile recruitment of lobsters has received little attention in Puerto Rico (Boardman & Weiler, 1982; Bohnsack et al., 1991; Monterrosa, 1991).

Commercial concrete blocks have been used for enhancing juvenile habitat (Davis, 1978, 1985; Cruz et al., 1986), but there is no evidence that these increase the number of juveniles in an area (Lozano-Alvarez et al., 1994). These types of shelters have not been adequately evaluated for juvenile recruitment in Puerto Rico. Larger cement shelters have been shown to increase the number of juveniles (Briones-Fourzán et al., 2007).

MATERIAL AND METHODS

Study sites

In October 2002, two sets of ten stations were placed at two different sites off the west coast of Puerto Rico. The first set (stations 1-10) was located at El Ron Reef (18°06.344′N 67°16.046′W) (fig. 1). The second set (stations 11-20) was located close to the Tourmaline area (18°08.581′N 67°18.324′W) (fig. 1).

The area where the first set is located is a shallow sea grass bed habitat associated with a reef. The depth contour is from 2 to 3 m. *Thalassia testudinum*

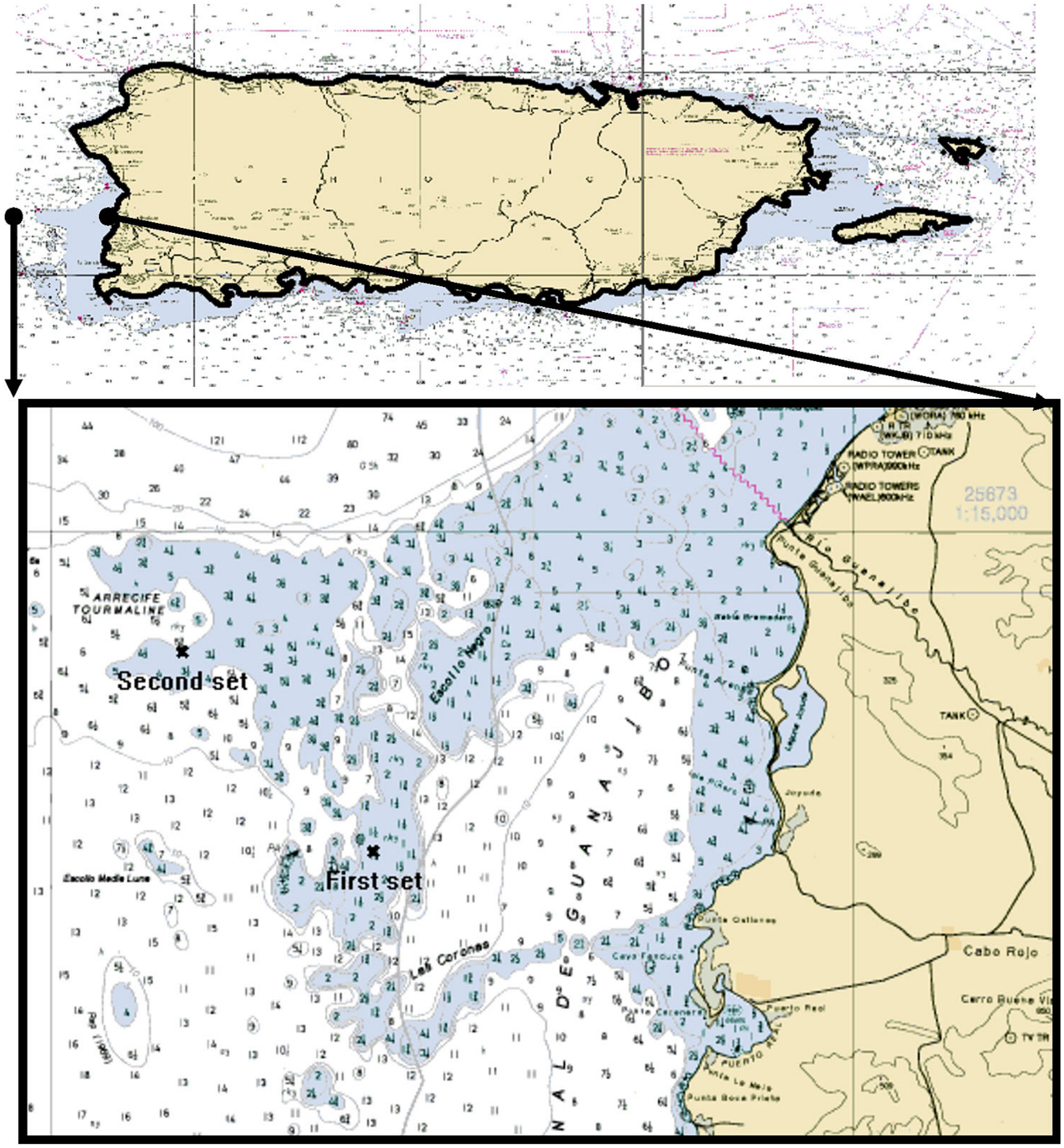

Fig. 1. Map of Puerto Rico with the location of the artificial shelter sites for *Panulirus argus* (Latreille, 1804) in the inset.

Banks ex König, 1805, is the predominant sea grass. Visibility (0.5-30 m) varies with water currents. The first station is adjacent to the reef. The next nine stations were placed in the sea grass bed largely parallel to the reef and approximately 10 m from it. The shelters were placed at least 10 m apart.

The area of the second set is a hard bottom habitat with some hard corals and gorgonians. Average depth on the site is 10 m. Visibility (3-35 m) varies with water currents, which sometimes are quite strong. The shelters were placed at least 10 m apart.

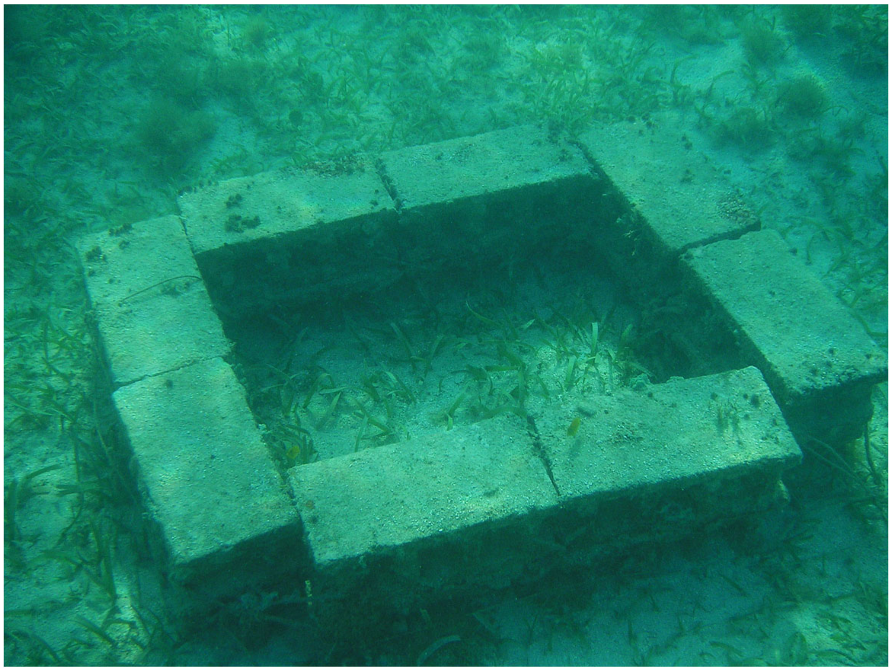

Fig. 2. Lobster artificial shelter as used in this study, to entice juveniles of *Panulirus argus* (Latreille, 1804).

Shelters

On each station a lobster artificial shelter was constructed. The shelter was built using 16 cement blocks. Eight of the blocks were placed on the seafloor forming a square shape, two cement blocks per side. The other eight blocks were placed on top of the first layer of blocks (fig. 2). The blocks were tied to each other with nylon rope. Identification numbers were assigned to each shelter. Numbers 1 to 10 were assigned to the shelters in the first set (shallow). Number 11 to 20 were assigned to the shelters in the second set (deep). Acrylic identification tags were attached to each shelter with their ID number engraved on it. In every other station the shelter was covered with a black canvas. Stations with covered artificial shelters were: 2, 4, 6, 8, 10, 11, 13, 15, 17 and 19. The canvas was held in place by tying it with steel wire to four steel rods that were nailed into the sea floor, one on each corner of the square. A cable was tied from shelter to shelter to make the locating of stations easier under conditions of low visibility and high currents.

Size classes

A variety of size classes have been assigned to juvenile lobsters (table I). Some of these are apparently arbitrary while others attempt to relate to various stages in the development or behavior of the juveniles. Unfortunately, there has been little agreement about the size ranges of these functional size classes (table I). Possibly regional variation is to blame. Our size classes: small juvenile 15-25 mm, medium

TABLE I

Some examples of juvenile Caribbean spiny lobster, *Panulirus argus* (Latreille, 1804)

SD	CL	SD	CL	SD	CL	SD	CL	Reference
Early[1]	<20	Later[2]	20-65	–	–	–	–	Marx & Herrnkind (1986)
Algal[3]	8-12	Transitional[4]	16-20	Post[5]	24-28	–	–	Smith & Herrnkind (1992)
Algal[3,6]	8-12	Transitional[4]	15	Post[5]	24-28	–	–	Childress & Herrnkind (1994)
Small	<50	–	–	–	–	Large	>50	Lozano-Alvarez et al. (1994)
New[7]	8-15	Older[8]	20-45	–	–	–	–	Acosta & Butler (1997)
Algal	6-15	Postalgal	26-35	–	–	Late	>35-<70	Buttler et al. (1997)
Algal	5-15	Transitional	16-25	Post[5]	26-35	Late	36-65	Minerva Arce et al. (1997)
Small	7-12	New[9]	<26	Active	26-50	Subadults	51-76	Acosta (1999)
Post[10]	6.1-16.5	Juvenile	16-44	–	–	Juvenile	45-76	FAO (2000)
Algal	5-15	Transitional	16-25	Postagal	26-36	–	–	Berger & Butler (2001)
Algal	5-15	Postalgal	15-45	–	–	Subadults	45-80	Briones-Fourzán et al. (2003)
Juvenile	26-35	–	–	Late	>35-<70	Subadult	70-76	Huitric (2004)
Small	15-35	–	–	Large	35.1-50	–	–	Briones-Fourzán et al. (2007)
Algal	7-25	Postalgal	25-45	–	–	Subadults	45-79	Briones-Fourzán et al. (2009)
Early	10-15	Juvenile	15-44	–	–	Late	45-80	Cox et al. (2008)
–	–	Small	15-25	Medium	28-51	Large	53-76	This study

SD, juvenile size designation; CL, carapace length (in mm).

[1] Early benthic algae-dwelling juvenile.

[2] Later crevice-dwelling juvenile.

[3] Algal phase juvenile.

[4] Transitional phase juveniles.

[5] Post-algal phase juvenile.

[6] Also 8-14 mm.

[7] New settlers, also called small juveniles (<15 mm).

[8] Also called larger juveniles (>20 mm).

[9] New settlers to post cryptic juveniles.

[10] Postpuerulus stage or algal phase.

juvenile 28-51 mm, and large juvenile 53-76 mm carapace length, roughly agree with the post-algal or transitional juveniles, late or active juveniles, and subadults of others (table I).

Counting and measuring

Starting in March 2003 the stations were visited once a month to count and measure juvenile lobster recruits. Covered shelters were opened to observe presence of recruits on the inside of the shelter. A graduated measuring stick was carefully placed beside each juvenile, the carapace length taken, and the stick removed with as little disturbance as possible. On our last visit, 23 February 2004, the canvases were removed to avoid damage to the adjacent areas by their eventual displacement. Standard safety procedures were employed in all scuba dives.

Statistics

Analysis was made with a mixed model ANOVA for data on juvenile lobster counts from shelters that were either covered or uncovered and followed for 12 months. The analysis was carried out using PROC MIXED in SAS with shelter condition (covered/uncovered) and month as fixed effects and shelters nested within cover type as random effects. The data were log($\ln + 1$)-transformed to stabilize the variance. A linear contrast was used to make planned comparisons among counts taken from August to June and those from February to July.

RESULTS

Shallow seagrass bed vs. deeper hard bottom

No juvenile lobsters were found in the deep shelters. Large juveniles and adult lobsters (>76 mm carapace length) were observed in the vicinity of the deep shelters.

In the shallow shelters, 158 juvenile lobsters were found and measured. Most (113) or 71.5% were small juveniles, 40 or 25.3% were medium juveniles, and 5 or 3.2% were large juveniles (table II).

Preferred shelters

Most of the juvenile lobsters (85) or 53.8% were found in shelter 4 (table II). Furthermore, most of each size class were also found in this shelter (54 small or 47.8%, 26 medium or 65.0%, and 5 large or 100%). Most all (74.4%) or 118 juveniles were found in shelters 3 and 4. In three shelters (7, 9, 10) only a single

TABLE II

Number of juvenile Caribbean spiny lobster, *Panulirus argus* (Latreille, 1804) (small, 15-25 mm; medium, 28-51 mm; large, 53-76 mm, carapace length), found at each shallow shelter (c, covered; u, uncovered)

Shelter	Small	Medium	Large	Total
1u				0
2c	5	1		6
3u	29	4		33
4c	54	26	5	85
5u	12	3		15
6c	3			3
7u		1		1
8c	8	5		13
9u	1			1
10c	1			1
Total	113	40	5	158

juvenile lobster was found and in shelter (1) none were found (table II). In general, the shelters (2-5, 8) that attracted the most small juveniles ($n = 5\text{-}54$, 21.6 average) also attracted the most medium juveniles (1-26, 7.8 average; table II). Shelter 10 was the exception with one medium juvenile and no small juveniles. Only the most successful shelter (4) had large juveniles (table II). Shelters 3 and 4 had significantly more juveniles than the other shelters ($P = 0.034$ for shelter 3 and $P = 0.002$ for shelter 4).

Seasonal recruitment

Most juvenile lobsters (119) or 75.3% were found during the examinations in August through January (table III). This was also true in every size class with 78 small juveniles (69.0%), 30 medium juveniles (75.0%), and 3 large juveniles (60.0%). Small juveniles were found throughout the year, medium juveniles were found in every month except March, large juveniles were only seen in spring and summer (table III). Significantly more juveniles occurred from August through January than from February through July ($F_{1,88} = 22.89$, $P < 0.001$).

Covered vs. uncovered shelters

Most juvenile lobsters (108, or 68.5%) were found in covered shelters (table II). This was also true for all size classes (71 small or 62.8%, 32 medium or 80.0%, and 5 large or 100%). However, much of this result is due to the preponderance of juveniles found in shelter 4, while other covered and uncovered shelters had similar numbers of juveniles (e.g., No. 5 covered with 15, No. 8 uncovered with

TABLE III

Number of juvenile Caribbean spiny lobster, *Panulirus argus* (Latreille, 1804) (small, 15-25 mm; medium, 28-51 mm; large, 53-76 mm, carapace length), found during each monthly examination

Date	Small	Medium	Large	Total
25 March 2003	2			2
24 April 2003	6	2		8
23 May 2003	4	2	1	7
27 June 2003	5	2	1	8
24 July 2003	5	3		8
29 August 2003	12	2	2	16
25 September 2003	16	5	1	22
21 October 2003	14	8		22
21 November 2003	22	2		24
19 December 2003	14	9		23
22 January 2004	8	4		12
23 February 2004	5	1		6
Total	113	40	5	158

13; No. 9 uncovered with 1, No. 10 covered with 1; table II). The number of juveniles in covered shelters was not significantly different from the number found in uncovered shelters ($F_{1,88} = 0.34$, $P = 0.58$).

DISCUSSION

Shallow seagrass bed vs. deeper hard bottom

Previous studies of lobster recruitment have found many more recruits on hard substratum than in sea grass beds (as summarized by Butler et al., 2006; Behringer et al., 2009). Our results show just the opposite; however, this may be an effect of depth as the sea grass samples were at 2-3 m and the hard substratum at approx. 10 m.

Juvenile lobsters were found on experimental fish net pens and later large numbers were found on submerged commercial fish net cages in Puerto Rico (E. H. Williams, unpubl. data). Many of these juveniles were on nets at a depth of 10 m or greater. However, our deeper, hard bottom shelters did not attract any juvenile lobsters.

Our results would suggest that the juvenile lobsters did not naturally recruit to the netting, but rather were strained into the netting by the currents. This may be another reason to place fish cages off shore where they cannot remove juvenile lobsters that would have ordinarily settled in the shallows. So many juvenile lobsters were found in the netting that this has been suggested as a source of lobsters for culture (Davis et al., 2007). A few of these cages should not eliminate enough juvenile lobsters to be of any importance, but dozens, or hundreds, of giant cages in a row might strain out most of the juvenile lobsters attempting to recruit in an area. This may be another unforeseen problem of a new culture method. However, this should be solved by moving the cages offshore.

Preferred shelters

Childress & Herrnkind (2001) suggested that the "guide effect" of juvenile lobsters already present in a den allowed new recruits to more quickly find shelter and caused gregarious grouping. This could help to explain why some (Nos 3, 4, 5, 8; table III) of our shelters had so many more recruits (average 36.5) than others (Nos 1, 2, 6, 7, 9, 10; table III; average 3). For example, the shelter with the most recruits (No. 4, 53.8%) had lobsters at the first monthly examination, unlike any other shelter, and possibly through the guide effect, attracted recruits before every monthly examination. The shelter with the second most recruits (No. 3, 20.9%) had recruits by the second monthly examination, a feat only matched by shelter No. 6, and had slightly more recruits that month (2 small and 1 medium juveniles vs. 2 small). The other shelters first had recruits for 4-11 months (average 7.3 months) after the shelters were deployed and, thus, would have had less time for guide effect to attract recruits. Childress & Herrnkind (2001) employed 28-49 mm CL juveniles in their experiments. This was similar to our medium juveniles (28-51 mm CL). Ratchford & Eggleston (1998) found that den choice in lobsters was influenced by conspecific odors as early as 15 mm CL.

Lozano-Alvarez et al. (1994) also had skewed results with one group of similar cement-block shelters recruiting 82.0% of the juvenile lobsters and most other shelters none. They suggested that natural habitat differences were responsible for a few traps attracting most of the juveniles. In our case there were no discernable habitat differences and two shelters still attracted most of the juveniles.

Butler et al. (2010) found low variability among sites in Honduras, southern Mexico, and Venezuela, but high variability among sites in Florida, San Andres Islands, Puerto Rico, and northern Mexico. Our sites also had high varability. They found recruitment magnitude varied locally, but generally increased (lowest to highest) from Puerto Rico, San Andres Islands, Honduras, Mexico, Venezuela, to Florida.

Callwood (2016), in a study based on interviews and models, suggested differences in condo recruitment among habitat types, in the Bahamas. She also thought some recruitment was local and some distant.

Juveniles were not removed from the shelters; therefore, small juveniles could have grown into medium juveniles and medium juveniles could have gown into

Fig. 3. Total number of lobster, *Panulirus argus* (Latreille, 1804), recruits at the shallow artificial shelters.

large juveniles measured later within the same shelters. Since these were not tagged or marked this survival is uncertain; however, 38 of the 40 medium juveniles were preceded by a month or more by small juveniles in their shelter as were all 5 large juveniles.

Seasonal recruitment

FAO (2000) reported the maximum settling periods in Cuba, the Mexican Caribbean, Jamaica, Antigua, Costa Rica and Bermuda were August to December, but February to March in the Florida Keys. Our results were similar to these previous Caribbean studies with the exception of having more recruits one month later (August to January, table III, fig. 3). The study by Butler et al. (2010), quite differently, found peaks in Puerto Rico from February to April. Other reports of recruitment peaks are somewhat confusing and contradictory (table IV). More work is needed to resolve these discrepancies.

Covered vs. uncovered shelters

Lozano-Alvarez et al. (1994) used covers over their shelters similar to those employed in the present study. They found no difference in recruitment between shelters with and without covers. In the present study, shelters with covers had more juveniles than those without covers; however, this result was largely due to the preponderance of juveniles in one shelter. The cover alone cannot explain the success of this shelter since adjacent covered shelters had few juveniles. Other adjacent covered and uncovered shelters had approximately the same number of juveniles.

TABLE IV

Major (M) and Minor (m) peaks of Caribbean spiny lobster, *Panulirus argus* (Latreille (1804), recruitment

Country/Island	Month												Reference
	J	F	M	A	M	J	J	A	S	O	N	D	
Jamaica							M			M	M		Young (1992)
								M	M	M	M	M	FAO (2000)
							M			M	M		Meggs (2005)
	M	M	M	M									Cooke-Panton (2015)
Antigua					M								Bannerot et al. (1992)
Bermuda								M	M	M	M	M	FAO (2000)
Costa Rica								M	M	M	M	M	FAO (2000)
	M	M			m					m			Gonzalez & Wehrtmann (2011)
Cuba								M	M	M	M	M	FAO (2000)
Mexico								M	M	M	M	M	FAO (2000)
Florida		M	M										FAO (2000)
		M	M	M						m	m	m	Butler et al. (2010)
St. Thomas					M								Gordan & Vasques (2005)
Bimini	M								M		M		Alfonzo & Gruber (2007)
W Caribbean										M	M	M	Butler et al. (2010)
Puerto Rico		M	M	M						m	m	m	Butler et al. (2010)
	M									M	M	M	This study
Venezuela		M	M	M						m	m	m	Butler et al. (2010)
Brazil			M	M			M	M	M				Cruz et al. (2015)
Colombia			M	M				M	M	M	M		Jaimes et al. (2016)

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