

Lobster Puerulus Settlement Studies

JASON S. GOLDSTEIN

Center for Marine Biology

University of New Hampshire

Zoology Department, 135 Rudman Hall

Durham, New Hampshire 03824 USA

ABSTRACT

The puerulus (postlarval) stage of spiny lobsters represents a critical and pivotal life-history link between the long-lived oceanic phyllosoma and the benthic dwelling adult-phase juvenile. Although great strides continue to within this realm of lobster research, there remain major gaps with respect to quantifying potential “connectivity” among populations as well as the ecological requirements and attributes for species that reside in remote habitats or are of non-commercial fishery interest. Through cooperative monitoring programs, The Puerulus Identification Project (PIP) seeks to gather, collate and disseminate current and additional data on the ecological requirements, natural settlement zones and early habitat shifts of pueruli throughout the Caribbean where lobster remains actively and intensely fished. Although not limited to any one species, the Caribbean spiny lobster, *Panulirus argus*, is the focal animal for this survey based on its immense economic and social significance throughout its range. Monitoring and collating electronically-linked data on the magnitude of puerulus recruitment to coastal areas around the Caribbean region could help elucidate more detailed patterns of postlarval influx, provide specimens for research, and help to model correlations of settlement to habitat and predictive patterns of recruitment leading to potential forecasting of good or bad years of fishery catch.

KEY WORDS: Caribbean spiny lobster, collectors, connectivity, puerulus

El Proyecto de Identificación de Puerulus (PROYECTO PIP): “Conectando los puntos” a través del Caribe

La etapa de puerulus (postlarval) de langosta espinosas representa una conexión crítica y esencial de su vida entre el phyllosoma oceánico y el fase bentónico juvenil-adulto. Aunque gran pasos hayan sido y continúan ser hecho dentro de este reino de investigación de langosta, todavía queda areas de investigación, especialmente con respecto a requisitos y atributos ecológicos para las especies que residen en habitates remotos y en que no hay intereses comerciales. A través de programas cooperativos, Proyecto PIP reunirá, cotejará y difundirá datos adicionales sobre los requisitos ecológicos, las zonas de reclutamiento, y cambios de habitat de pueruli en el Caribe. Información de

este tipo sería especialmente importante para directores de pesquerías importantes y proporcionaría predicciones valiosas de períodos buenos o malos en el futuro. Específicamente, los objetivos de Proyecto PIP incluye: (1) una evaluación y descripción de los requisitos ecológicos de pueruli para definir las zonas de reclutamiento; (2) calcular el número de etapas de puerulus y la longevidad de cada etapa; (3) comparar los tamaños y proporciones de pueruli a adultos; (4) evaluar las tendencias evolutivas en la ecología y el comportamiento de puerulus que ha resultado debido a cambios en el ambiente; (5) asistir en el diseño de colectores artificiales para especies que requieren programas de monitoreo así como nuevas empresas comerciales que piensan coleccionar pueruli para acuicultura. El enfoque de este proyecto será triple e incluye un estudio a través del Caribe sobre puerulus, la compilación de una base de datos emparejada con una biblioteca de fotos digital, y la conservación de archivos de puerulus para investigaciones en el futuro.

PALABRAS CLAVES: Langosta espinosas, puerulus, colectores, atributos ecológicos

INTRODUCTION

Spiny lobsters comprise one of the most economically valuable and ecologically significant marine fishery resources in the Caribbean. The Caribbean spiny lobster (*Panulirus argus*, Latrielle 1804) fishery in the Western Central Atlantic for example is one of the largest in the world and constitutes the biggest single-species fishery in Cuba, contributing 60 - 65% of the country's gross income in fisheries products (Baisre 2000). Throughout the Mesoamerican coast, spiny lobster sustains the economy and social fabric of many important regional fisheries. The FAO Year Book of Fishery Statistics reports that along the Central American coast, between 1975 - 1997, more than 20% of Caribbean spiny lobster landings originated from this region (FAO 2000, Ehrhardt 2000). In the US state of Florida *P. argus* is at the apex of a commercial fishing history that spans over 100 years and includes a popularized and highly intense recreational fishery (Hunt 2000, Sharp et al. In press). Additionally, Florida spiny lobster catches consistently remain the State's second most valuable commercial fishery after pink shrimp (Muller et al. 1997).

Like all spiny lobsters worldwide, the Caribbean spiny lobster possesses a complex, and protracted larval stage (phyllosoma) that can remain especially elusive, easily exceeding six months (Lewis 1952, Kittaka 1994). During this long-term oceanic existence, phyllosomata are subjected to an assortment of physical oceanographic elements (e.g. currents, fronts, eddies, gyres) coupled to a suite of active and innate behavioral traits (e.g. swimming ability, vertical migration) that allows a wide dispersal resulting in larval transport to near-shore environments, later supporting coastal fisheries in a new home. Following these 11 or so distinct phyllosomal stages, a postlarval (puerulus) stage develops that represents a critical and pivotal life-history link between the long-lived, phyllosoma and the benthic dwelling adult-phase juvenile. The puerulus stage ($\approx 6.5 - 7.0$ mm CL) is characterized as a clear, non-feeding,

fusiform-shaped, strong swimming lobster that, at an undetermined distance from shore, actively seeks appropriate settlement habitat, primarily in near-shore environments (Acosta and Butler 1999). The constant interchanges of biotic and abiotic factors operating at various temporal and spatial scales (i.e. recruitment variability) acts to influence the distributions of these ongoing recruitment episodes and thus shapes the population dynamics and stability of marine ecosystems (Gaines and Roughgarden 1985, Cowen 2000, Sale and Kritzer 2003). Consequently, there is a directed effort at understanding how both physical and bio-mechanistic processes harmonize in influencing these critical life history phases, eventually linking them to adult (fished) populations. (Katz et al. 1994, Cobb et al. 1997, Moksnes et al. 2003).

Although great research strides have been and continue to be made within the realm of spiny lobster early life history, there are still major gaps, particularly with respect to ecological requirements and habitat attributes for species that reside in remote habitats or are of non-commercial fishery interest (Butler and Herrnkind 2000). For example, the reclusive and obligate reef dwelling spotted spiny lobster, *Panulirus guttatus*, although presently not of significant commercial value, does warrant more investigation as a species whose pueruli utilize and occupy a very different suite of benthic habitat types as does its counterpart, *P. argus*. Recent ecological studies and surveys of *P. guttatus* population dynamics have documented various and important aspects of puerulus and juvenile spiny lobster ecology, although more is needed (Briones-Fourzan and McWilliam 1997, Lyons and Hunt 1997, Sharp et al. 1997, Robertson and Butler 2003). There also lacks a centralized source for general puerulus information from which to access, both from the historical literature and from ongoing projects. Recent research of the 50 or so palinurid species provides reasonably detailed morphological descriptions of these phases for identification (McWilliam 1995) and should be expanded upon and correlated with both coastal habitat and ecological dynamics among regions.

In light of what information exists and what we can further gather, PIP seeks five main aims that include:

- i) Assessing the comparative ecological requirements of pueruli, helping to define a range of natural settlement zones (Figure 1),
- ii) Assessing the number of puerulus stages and the longevity of each stage,
- iii) Comparing size ratios of pueruli to adults,
- iv) valuating past evolutionary trends in puerulus behavior and ecology that have resulted from ecological and environmental changes, and
- v) Assisting in the design of specialty artificial collectors for species and regions that still require effective monitoring programs as well to potential commercial enterprises that intend to perhaps harvest pueruli for future aquaculture ventures.

Although not limited to any one species, the Caribbean spiny lobster, *Panulirus argus*, is the focal animal for this survey based on its immense economic and social significance throughout its range.

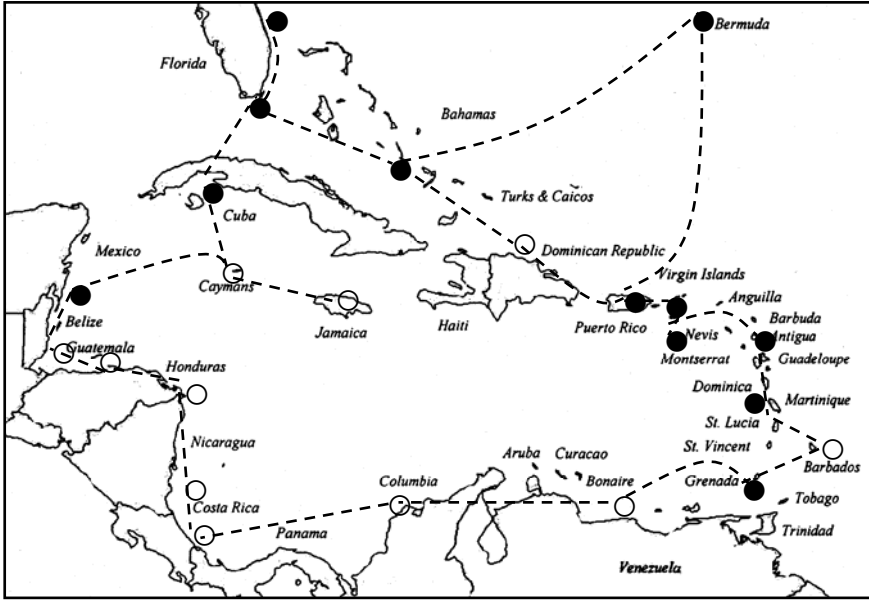


Figure 1. “Connecting the Dots”: A graphic summary of historical and mostly published puerulus recruitment and monitoring study areas (●) and potentially new coastal regions (○) that could provide new data and ecological links to other areas throughout the Caribbean.

METHODOLOGY AND APPROACH

The approach in carrying out this long-term project will be threefold:

- i) A comprehensive Caribbean-wide puerulus field survey conducted via institutional and individual participation,
- ii) The compilation of a relational database coupled with an interactive digital photo library, and
- iii) The preservation of archival puerulus material via museum cataloging for future research.

Survey and Field Collections

For decades, field-collector studies based on the fundamental designs of Witham and Phillips have served as templates and experimental units for the collection, quantification, monitoring, and research of spiny lobster pueruli worldwide (see Phillips 1994, 1995 for reviews, also Witham 1968, Figure 2). Subsequently, both large and small-scale monitoring programs in the Caribbean have documented puerulus recruitment trends along with seasonal variability for particular locations (summarized in Table 1). Although there has been tremendous and in some instances, multi-national cooperative efforts, with respect to puerulus monitoring, with the exception of Mexico, there still remains a paucity of monitoring studies throughout the Mesoamerican region

(Figure 1). Based on their rudimentary design and inexpensive cost, the use of Witham or modified Witham collector units for future planning and design of monitoring studies particularly in Central America, where fishing effort is high, is encouraged.

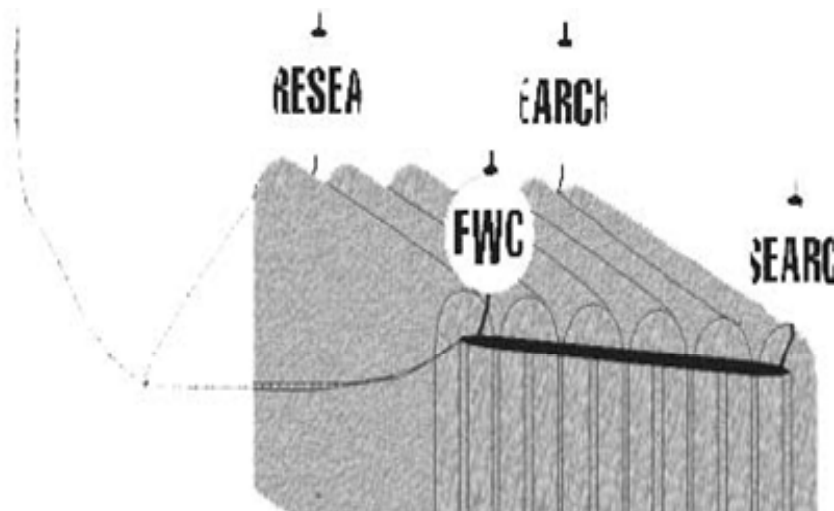


Figure 2. 'Witham-style' puerulus (postlarval) lobster collector using PVC, airfilter material, rope, and buoys. (redrawn with permission from FWRI)

Relational Database and Digital Library

Relational databases (RDs) provide an efficient and cost-effective mechanism for archiving and retrieving linked data. RD operations are constructed from linked data tables and subsequent queries are performed on that data (i.e. tables themselves), producing output tables (Sigler and Flis 1998). As a result, RDs serve managers and scientists alike who want to rapidly access critical information and query multiple links in this case, between factors such as habitat, region, and puerulus characteristics. PIP will develop a RD using Microsoft Access. One such model is the RD LarvalBase[®] (<http://www.larvalbase.org> 2005), a global and comprehensive information system of data on fish larvae that is relevant to the field of finfish aquaculture. LarvalBase is an excellent MS-Access-designed RD, although it will eventually be converted to the more efficient SQL (structured query language)(B. Ueberschaer Pers. comm.). From this RD will evolve an online digital library of graphics consisting of digitized puerulus pictures linked with habitat areas from around the region. A potential user would be able access pueruli online for identification, as well as descriptive links (e.g. lat/long, collectors used, habitat types,) to the locations from where they are being monitored.

Table 1. A summary of historical and mostly published puerulus recruitment and monitoring studies for *P. argus* and *P. guttatus* throughout the Caribbean region

Species	Collector Method	Region / Country	Reference
<i>P. argus</i>	Witham	Florida, USA	Acosta and Butler 1999, Heatwole et al. 1991, Herrnkind and Butler 1986, Herrnkind and Butler 1994, Little 1977, Little and Milano 1980, Witham 1968, Matthews et al. (unpub data)
	Channel Nets	Florida Keys, USA	Yeung et al. 2001, Butler and Goldstein (unpub data)
	Witham (modified)	Bahamas	Eggleston et al. 1998
	Witham	Bermuda	Ward 1992
	Witham	Antigua	Bannerot et al. 1991 and 1992, Rytner et al. 1988
	Witham	St. Thomas, USVI	Quinn and Kojis 1997, Quinn et al. 1998, Kojis et al. 2003
	Witham	St. Croix, USVI	Cox et al. (unpub data)
	Witham (modified)	Puerto Rico	Monterrosa 1991
	Witham	Martinique	Ricelet 1998
	Witham	Grenada	Galinski 1995 (unpub data)
<i>P. guttatus</i>	Phillips	Cuba	Cruz et al. 1991, Phillips et al. 1994
	GUSI	Mexico	Briones-Fourzan and D. Gutierrez-Carbonell 1992, D. Gutierrez-Carbonell et al. 1992
	GUSI and plankton tows	Mexico	Briones-Fourzan and McWilliam 1997
	SCUBA	Florida, USA	Sharp et al. 1997

Archival Information

The Museum of Comparative Zoology (MCZ) at Harvard University was founded in 1859 through the efforts of zoologist and scholar Louis Agassiz (1807-1873). The Department of Invertebrate Zoology houses some of the most extensive and historically important collections available to researchers today. There are an estimated 307,100 lots of approximately one million specimens in the collections; the crustacean collection (> 215,000 specimens) is one of the largest in the U.S. (Johnston Pers. Comm.). Through their generosity and cooperation, MCZ will serve as a repository for this lobster material. Prospective sub-samples will be digitally archived and kept within the RD for future queries and research applications. Specimens that are deposited will be catalogued and preserved in accordance to museum protocols and would be available for future research projects to visiting scientists, graduate students, and others.

Participation

Co-operative participatory relationships will continue with active and potential fishery managers, scientists, and fishermen throughout the region. These individuals will be contacted via email and from FAO stock assessment meetings in providing *P. argus* and other pueruli specimens from the following key locations, but not limited to: Florida Keys, Cuba, Bahamas, Bermuda, Mexico, Belize, Puerto Rico, St. Croix, Barbados, Honduras, and Venezuela.

DISCUSSION

One of the most significant challenges within this fishery remains the lack of basic data in terms of quantifying the influx of new postlarval lobster recruits to some regional areas. Gathering more of this kind of data lends itself to further understanding aspects of local and regional population structure and stability, health, and habitat quality of known juvenile nursery grounds. Gaining insight into these areas will allow for better, more informed decisions of the fishery in the future. Attaining such a level of knowledge, however, requires small steps and well designed science coupled with persistent funding and consistent regional participation. Successful campaigns and long-term programs for postlarval lobster surveys and monitoring programs are documented in such places as Western Australia, Cuba, and the Florida Keys. Understanding some of the early life history aspects through monitoring and exploratory science has allowed fisheries managers in these regions the benefit of affording local fishermen of the fragility and sometimes cyclical nature of marine stocks. Getting to a level of being able to make predictions of recruitment to the fishery (as is the general case for Western Australia) requires, as a prerequisite, a significant correlation between postlarval supply and juvenile abundance.

Applications and Benefits

Along with other scientists and fishery managers, the potential “connectivity” among lobster populations is a reality throughout the Caribbean, linked intimately by physical oceanographic elements and biological characteristics intrinsic to these animals. PIP strives to gather better information starting at the pre-juvenile (puerulus) level in order to ascertain, explore, and apply our understanding to fisheries and ecological disciplines. Applications for such data would include but not be limited to:

- i) Obtaining a broad and descriptive assessment of comparative ecological requirements of pueruli through survey information, helping to define a range of natural settlement zones,
- ii) Assessing the number and type of puerulus stage(s) among species caught and the longevity of each stage and comparing the size ratio of the puerulus to adult,
- iii) Acquiring additional data on the genetic stock structure and sources of recruitment in the Caribbean using microsatellite and other DNA sequencing technologies (see Silberman et al. 1994),
- iv) Investigating the physiological differences of pueruli (e.g. nutritional condition) over spatial and temporal time scales and their implications on settlement success (Jeffs et al. 2005) (Figure 3),
- v) Identifying settlement indices and their consequences on recruitment to specific habitat areas, and
- vi) Assisting in the design of specialty artificial collectors for many species that still require effective monitoring programs as well as assistance to new commercial enterprises (Mills and Creer 2004) that intend to harvest pueruli and grow them to marketable sizes.

Additionally, understanding aspects of climatic variability and oscillation may, over time, explain some of the variation in puerulus settlement. The El Nino Southern Oscillation (ENSO) for example is the most famous and well studied of all the decadal scale climate variations. Caputi and Brown (1993) show a clear correlation between ENSO and the strength of puerulus settlement in conjunction with the Leeuwin Current in Western Australia. Booth (1989) documents onshore wind frequencies and the seasonal effect it has on the puerulus settlement index of *Jasus edwardsii* in New Zealand. The expansion of a more widely spread and methodologically connected Caribbean-wide study will help us two-fold in understanding the mechanisms of environmental variation and its effects on both annual and seasonal puerulus settlement across locations as well how spawning stock biomass is being influenced concomitantly.

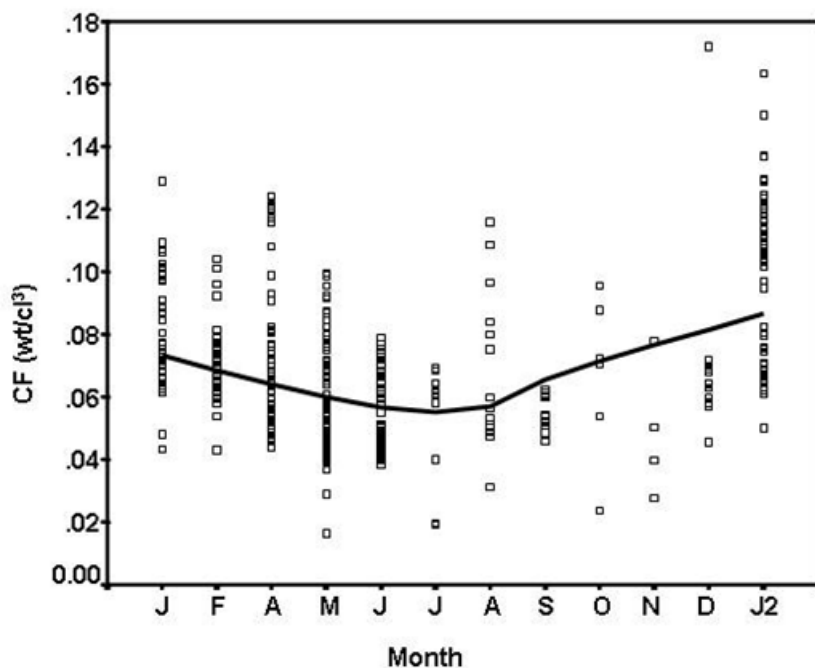


Figure 3. Condition factor (CF) as a proxy for nutritional condition over time (2002-2004, duplicate months pooled) for pueruli ($n = 683$) of *P. argus* monitored and collected at three sites in the Florida Keys ($n = 683$) (regression model constructed from the Loess deterministic function, modified from Goldstein 2005).

ACKNOWLEDGEMENTS

As a cooperative project that invites participants from throughout the Caribbean thanks and gratitude are extended to many: the Florida Wildlife Research Institute (FWRI) in Marathon, Florida for their intellectual and logistical support including: R. Bertelsen, T. Matthews, B. Sharp, L. Cox, G. Delgado, and J. Hunt as well as M.J. Butler IV of Old Dominion University. The author also wishes to thank A. Johnston of Harvard MCZ and R. George for his ideas, support and encouragement of this project. Partial funding for this project has been obtained by the generosity and interest of Darden Restaurants and the Darden Environmental Trust. This paper was presented as a poster presentation at the 57th Annual Gulf and Caribbean Research Institute annual meeting in St. Petersburg, Florida USA, November 8-12, 2004.

LITERATURE CITED

- Acosta, C.A. and M.J. Butler, IV. 1999. Adaptive strategies that reduce predation on Caribbean spiny lobster postlarvae during onshore transport. *Limnology and Oceanography* **44**:494-501.
- Baisre, J.A. 2000. The Cuban Spiny Lobster Fishery. Pages 135-152 in: B.F. Phillips and J. Kittaka, (eds). *Spiny Lobsters: Fisheries and Culture, 2nd Edition*. Fishing News Books, Oxford, England.
- Bannerot, S.P., J.H. Ryther, and S. Griffith. 1991. Progress on assessment of recruitment of postlarval spiny lobsters, *Panulirus argus*, to Antigua, West Indies. *Proceedings of the Gulf and Caribbean Fisheries Institute* **40**:482-488.
- Bannerot, S.P., J.H. Ryther, and M. Clark. 1992. Large-scale assessment of recruitment of postlarval spiny lobsters, *Panulirus argus*, to Antigua, West Indies. *Proceedings of the Gulf and Caribbean Fisheries Institute* **41**:471-486.
- Booth, J.D. 1989. Occurrence of the puerulus stage of the rock lobster *Jasus edwardsii* at the New Plymouth Power Station, New Zealand. *New Zealand Journal of Marine and Freshwater Research*. **23**:43-50.
- Briones-Fourzan, P.F. and D. Gutierrez Carbonell. 1992. Postlarval recruitment of the spiny lobster, *Panulirus argus* (Latreille 1804), in Bahia de la Ascension, Q.R. *Proceedings of the Gulf and Caribbean Fisheries Institute* **41**:492-507.
- Briones-Fourzan, P.F. and P.S. McWilliam. 1997. Puerulus of the spiny lobster *Panulirus guttatus* (Latreille, 1804) (Palinuridae). *Marine and Freshwater Research* **48**(8):699-706.
- Briones-Fourzan, P.F. and G. Contreras-Ortiz. 1999. Reproduction of the spiny lobster *Panulirus guttatus* (Decapoda:Palinuridae) on the Caribbean coast of Mexico. *Journal of Crustacean Biology*. **19**:171-179.
- Butler, M.J., IV and W.F. Herrnkind. 1992. Spiny lobster recruitment in south Florida: quantitative experiments and management implications. *Proceedings of the Gulf and Caribbean Fisheries Institute* **41**:508-515.
- Butler, M.J., IV and W.F. Herrnkind. 2000. Puerulus and Juvenile Ecology. Pages 276-301 in: B.F. Phillips and J. Kittaka, (eds.). *Spiny Lobsters: Fisheries and Culture, 2nd Edition*. Fishing News Books, Oxford, England.
- Caputi, N. and R.S. Brown. 1993. The effect of the environment on the puerulus settlement of the western rock lobster (*Panulirus cygnus*) in Western Australia. *Fisheries Oceanography*. **2**(1):1-10.
- Cobb, J., J.D. Booth, and M. Clancy. 1997. Recruitment strategies in lobsters and crabs: a comparison. *Marine and Freshwater Research* **48**:797-806
- Cowen, R.K., K.M.M. Lwiza, S. Sponaugle, C.B. Paris, and D.B. Olson. 2000. Connectivity of marine populations: open or closed? *Science* **287**:857-859.
- Cox, C. [2004-2005]. A survey of Caribbean spiny lobster, *Panulirus argus*, puerulus recruitment to Buck Island marine reserve, St. Croix, USVI, Unpublished data.

- Cruz, R., M.E. de Leon, E. Diaz, R. Brito, and R. Puga. 1991. Reclutamiento de puerulus de langosta (*Panulirus argus*) a la plataforma Cubana. *Revista de Investigaciones Marinas* **12**(1-3):66-75.
- Ehrhardt, N.M. 2000. The Atlantic Spiny Lobster Resources of Central America. Pages 153-168 in: B.F. Phillips and J. Kittaka, (eds.). *Spiny Lobsters: Fisheries and Culture, 2nd Edition*. Fishing News Books, Oxford, England.
- Eggleston, D.B., R.N. Lipcius, L.S. Marshall Jr., and S.G. Ratchford. 1998. Spatiotemporal variation in postlarval recruitment of the Caribbean spiny lobster in the central Bahamas: lunar and seasonal periodicity, spatial coherence, and wind forcing. *Marine Ecology Progress Series*. **174**:33-49.
- Food and Agriculture Organization of the United Nations. 2000. FAO Yearbook of Fishery Statistics – Catches and Landings, vol 80. *FAO Fisheries Series* **48**, FAO Statistics Series No. 134.
- Gaines, S. and J. Roughgarden. 1985. Larval settlement rate: A leading determinant of structure in an ecological community of the marine intertidal zone. *Proceedings of the National Academy of Sciences*. **82**: 3707-3711.
- Goldstein, J.S. [2005]. M.S. Thesis, Old Dominion University, Unpublished.
- Gutierrez-Carbonell, D., J.Simonin-Diaz, and P. Briones-Fourzan. 1992. A simple collector for postlarvae of the spiny lobster *Panulirus argus*. *Proceedings of the Gulf and Caribbean Fisheries Institute* **41**:516-527.
- Heatwole, D.W., J.H. Hunt, and B.I. Blonder. 1991. Offshore recruitment of postlarval Looe Key Reef, Florida. *Proceedings of the Gulf and Caribbean Fisheries Institute* **40**:429:433.
- Herrnkind, W.F. and M.J. Butler IV. 1986. Factors regulating postlarval settlement and juvenile microhabitat use by spiny lobsters, *Panulirus argus*. *Marine Ecology Progress Series* **34**:23-30.
- Herrnkind, W.F., and M.J. Butler, IV. 1994. Settlement of spiny lobsters, *Panulirus argus* in Florida: pattern without predictability. *Crustaceana*. **67**:46-64.
- Hunt, J.H.H. 2000. Status of the Fishery for *Panulirus argus* in Florida. Pages 189-199 in: B.F. Phillips and J. Kittaka, (eds.). *Spiny Lobsters: Fisheries and Culture, 2nd Edition*. Fishing News Books, Oxford, England.
- Jeffs, A.G., J.C. Montgomery, and C.T. Tindle. [2005]. How do spiny lobster post-larvae find the coast? *New Zealand Journal of Marine and Freshwater Research*. In press.
- Katz, C.H., J.S. Cobb, and M. Spaulding. 1994. Larval behavior, hydrodynamic transport, and potential offshore-to-inshore recruitment in the American lobster *Homarus americanus*. *Marine Ecology Progress Series* **103**:265-273.
- Kittaka, J. 1994. Culture of phyllosomas of spiny lobster and its application to studies of larval recruitment and aquaculture. *Crustaceana* **66**: 258-269.
- Kojis, B.L., N.J. Quinn, and S.M. Caseau. 2003. Recent settlement trends in *Panulirus argus* (Decapoda: Palinuridae) pueruli around St. Thomas, U.S. Virgin Islands. *Revista de Biología Tropical* **51**:17-24.
- LarvalBase[®]. 2005. <http://www.larvalbase.org>.

- Lewis, J.B., H.B. Moore, and W. Babis. 1952. The post-larval stages of the spiny lobster *Panulirus argus*. *Bulletin of Marine Science* **2**:324-337.
- Little, E.J. Jr. 1977. Observations on recruitment of postlarval spiny lobsters, *Panulirus argus* to the south Florida coast. *Florida Marine Research Publication* No. **29**.
- Little, E.J., Jr. and G.R. Milano. 1980. Techniques to monitor recruitment of postlarval spiny lobster, *Panulirus argus* to the Florida Keys. *Florida Marine Research Publication* **37**.
- Lyons, W.G. and J.H. Hunt. 1997. The puerulus of the spotted spiny lobster, *Panulirus guttatus* (Latreille 1804) (Crustacea:Decapoda). *Journal of Marine and Freshwater Research* **48**(6):491-495.
- Macmillan, D.L., B.F. Phillips, and J.A. Coyne. 1992. Further observations on the antennal receptors of rock lobsters and their possible involvement in puerulus stage navigation. *Marine Behavior and Physiology* **19**:211-225.
- McWilliam, P.S. 1995. Evolution in the phyllosoma and puerulus phases of the spiny lobster Genus *Panulirus* White. *Journal of Crustacean Biology* **15**(3):542-557.
- Mills, D. and B. Creer. 2004. Developing a cost-effective puerulus collector for the southern rock lobster (*Jasus edwardsii*) aquaculture industry. *Aquacultural Engineering* **31**(1-2):1-15.
- Moksnes, P.O., O. Hedvall, and T. Reinwald. 2003. Settlement behavior in shore crabs *Carcinus maenus*: why do postlarvae emigrate from nursery habitats? *Marine Ecology Progress Series* **250**:215-230.
- Monterrosa, D.E. 1991. Postlarval recruitment of the spiny lobster, *Panulirus argus* (Latreille) in southwestern Puerto Rico. *Proceedings of the Gulf and Caribbean Fisheries Institute* **40**:434-451.
- Muller, R.G., J.H. Hunt, T.R. Matthews, and W.C. Sharp. 1997. Evaluation of effort reduction in the Florida Keys spiny lobster, *Panulirus argus*, fishery using an age structured population analysis. *Journal of Marine and Freshwater Research*. **48**:1045-1058.
- Phillips, B.F. 1994. Design, use, and effectiveness of collectors for catching the puerulus stage of spiny lobsters. *Reviews in Fisheries Science* **2** (3):255-289.
- Phillips, B.F. 1995. Collectors for catching the puerulus stage of spiny lobsters: A summary. *Revista Cubana de Investigaciones Pesqueras* **19** (1):33-41.
- Quinn, N.J., and B.J. Kojis. 1997. Settlement variations of the spiny lobster (*Panulirus argus*) on Witham collectors in Caribbean coastal waters around St. Thomas, United States Virgin Islands. *Caribbean Journal of Science* **33**:251-262
- Quinn, N.J., B.J. Kojis, and C. Chapman. 1998. Spiny lobster (*Panulirus argus*) recruitment to artificial habitats in waters off St. Thomas, United States Virgin Islands. *Proceedings of the Gulf and Caribbean Fisheries Institute* **45**:759-777.
- Ricelet, E. 1998. *Recruitment and Culture Trials of the Caribbean spiny lobster Panulirus argus (Latreille, 1804) in Martinique*. PhD dissertation, University of Paris, Paris, France. 166 pp.

-
-
- Robertson, D.N. and M.J. Butler IV. 2003. Growth and size at maturity in the spotted spiny lobster, *Panulirus guttatus*. *Journal of Crustacean Biology* **23**:265-272.
- Ryther, J.H., W.A. Lellis, S.P. Bannerot, and J.A. Chaiton. [1988]. Crab and spiny lobster aquaculture. Part II Spiny lobster mariculture. Report 5380140.03(1), U.S. Aid Grant.
- Sale, P.F. and J.P. Kritzer. 2003. Determining the extent and spatial scale of population connectivity: decapods and coral reef fishes compared. *Fisheries Research* **65**:153-172.
- Sharp, W. C., J. H. Hunt, and W. G. Lyons. 1997. Life history of the spotted spiny lobster, *Panulirus guttatus*, an obligate reef-dweller. *Journal of Marine and Freshwater Research* **48**: 687-698.
- Sharp, W.C., R. D. Bertelsen, and V. R. Leeworthy. [2005]. Long-term trends in the recreational lobster fishery of Florida , United States: landings, effort, and implications for management. *New Zealand Journal of Marine and Freshwater Research*. In press.
- Sigler, L. and A.L. Flis. 1998. Utility and features of a customized PC Windows-based relational database for managing microbial strain data. *Journal of Industrial Microbiology & Biotechnology* **20**:86-89.
- Silberman, J.D., S.K. Sarver, and P.J. Walsh. 1994. Mitochondrial DNA variation in seasonal cohorts of spiny lobster (*Panulirus argus*) postlarvae. *Molecular Marine Biology and Biotechnology* **3**:165-170.
- Ward, J. 1992. Patterns of settlement of spiny lobster (*Panulirus argus*) postlarvae at Bermuda. *Proceedings of the Gulf and Caribbean Fisheries Institute* **39**:255-264.
- Witham, R.R., R.M. Ingle, and E.A. Joyce, Jr. 1968. Physiological and ecological studies of *Panulirus argus* from the St. Lucy estuary. *Florida State Board of Conservation Technical Series* **53**:31 pp.
- Yeung, C., D.L. Jones, M.M. Ciales, T.L. Jackson, and W.J. Richards. 2001. Influence of coastal eddies and counter-currents on the influx of spiny lobster, *Panulirus argus*, postlarvae into Florida Bay. *Marine and Freshwater Research* **52**:1217-1232.

BLANK PAGE