Large-Scale Assessment of Recruitment of Postlarval Spiny Lobsters, *Panulirus argus*, to Antigua, West Indies

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ABSTRACT

Twenty-eight floating collecting devices, constructed of PVC pipe and air conditioner filter material, were deployed, maintained, and sampled weekly from 28 August 1987 to 29 July 1988 in Antigua, West Indies for the purpose of assessing periodicity, magnitude, and distribution of recruitment of postlarval spiny lobsters to nearshore waters. Thirteen of these collectors were distributed randomly around the coastline within 50 m of shore to obtain unbiased estimates of relative abundance. Fifteen were deployed nonrandomly 1 m to 4.8 km from shore in order to increase area and number of habitat types sampled. Total sample size was 11,697. Combined with additional field experiments, 22,817 postlarval lobsters were collected. Recruitment was strongly correlated with moon phase. Largest samples occurred during the new moon and first quarter throughout the year. Recruitment during May was significantly higher than any other month. Practical aspects of large-scale recruitment studies in the Caribbean, including cost, attainable objectives, and applications of results, are discussed.

INTRODUCTION

Palinurid lobsters are highly valued fishery resources throughout much of their circumtropical-subtropical distribution. For this reason the more commercially important species have drawn considerable attention from researchers, particularly in the past two decades.

The western Atlantic spiny lobster, *Panulirus argus,* and the western Pacific rock lobster, *P. cygnus*, have perhaps been the most studied, followed by the spiny lobster *P. interruptus* and *P. marginatus.* A large proportion of these publications address aspects of the settlement of puerulus stage postlarvae because of the development of effective artificial collecting devices.

Witham *et al.* (1968) devised a collector effective for *P. argus* in Florida, and Phillips (1972) did the same for *P. cygnus* in Australia. Subsequently, a large number of papers have been published based on the results of regularly sampling these devices or variations thereof. These include quantitative estimates of relative magnitude and periodicity of recruitment within and/or between years for *P. interruptus* in southern California (Serfling and Ford, 1975), *P. marginatus* in the Hawaiian Islands (MacDonald, 1986), and *P. argus*

in southern Florida (Little, 1977).

Collector-based studies of *P. argus* pueruli in the tropical western Atlantic region indicate arrival during every month of the year, with higher settlement rates during the new moon and first quarter (Little, 1977; Little and Milano, 1980; Heatwole *et al.*, 1991, in southern Florida; Monterrosa, 1991, in Puerto Rico). Calinski and Lyons (1983) documented night swimming activity of arriving pueruli in Grenada but did not address seasonality of recruitment.

Heatwole *et al.* (1991) demonstrated that pueruli are physiologically capable of settlement 8 km offshore, and that temporal patterns and magnitude of recruitment at offshore sites may differ significantly from those near shore. Aspects of habitat selection and utilization by postlarvae in nearshore areas were documented by Marx and Herrnkind (1985) and Herrnkind and Butler (1986). Herrnkind *et al.* (1988) indicated that postlarval settlement may be adversely affected by heavy siltation.

Despite the abundance of literature on settlement of pueruli, little of the work is directly applicable to fishery management. Two exceptions are an estimation of stock-recruitment relationships (Morgan *et al.*, 1982) and prediction of commercial landings (Phillips, 1986), both based on data on settlement of *P. cygnus* puerulion collectors in western Australia. For *P. argus* in the Caribbean region, however, only work by Menzies and Kerrigan (1979) and Menzies (1981) attempted a large-scale experiment with direct management implications. The cost of construction, deployment, and sampling, combined with the paucity of catch data available for correlation, has prevented to date more holistic programs to monitor recruitment of *P. argus* in the region. While ongoing work provides biological insights into recruitment processes, samples are insufficient in size and areal coverage to have direct management application.

Even small-scale studies on recruitment of pueruli are scarce for the Greater and Lesser Antilles, the 3380 km (2100 mi) arc of islands comprising the northern and eastern borders of the Caribbean Sea. We know of only two publications from this region, both of which were based on small samples (Monterrosa, 1991; Puerto Rico, 166 total individuals collected; and Peacock, 1974; Antigua, n = 86).

The purpose of this paper is to describe the research objectives, methods, costs, logistics, general results, and potential applications of a large-scale assessment of recruitment of postlarval *P. argus* to Antigua, West Indies, from August 1987 through July 1988.

RESEARCH OBJECTIVES AND GENERAL APPROACH

The primary objective of the study was to estimate the relative magnitude of recruitment of postlarval *P. argus* to Antigua in sufficient temporal and spatial detail to derive a representative index of the abundance of postlarvae recruited to

the island over a period of one year. Given sufficient sample size, this would also enable documentation of time-related arrival patterns such as lunar periodicity and seasonal peaks, changes in spatial distribution of recruitment over time, and possible interaction between periodicity, spatial distribution, and physical oceanographic phenomena.

Our general approach was to deploy the maximum possible number of standard collecting devices in nearshore (less than 50 m from shore) and offshore (to 4.8 km from shore) sites around Antigua, sample each collector weekly for one year, and concurrently record as many relevant physical oceanographic parameters as possible.

STUDY AREA

Antigua is located at latitude 17°5' N, longitude 61°47' W on an extensive (2500 square km), shallow (usually less than 37 m depth) oceanic shelf along with the island of Barbuda. The shelf comprises the northeastern-most extension of the Lesser Antilles chain. The prevailing large-scale surface circulation in the vicinity of the shelf is the North Equatorial Current, which sweeps in a northeasterly direction. Local currents to at least 32 km (20 mi) offshore of Antigua were variable in direction and velocity according to data from swordfish longline vessels, but were usually northerly in the Atlantic Ocean east of Antigua during the study period.

MATERIALS, METHODS, AND STUDY SITES

Collector Construction

Each collector was constructed of a 1.9 cm (3/4 in) closed PVC pipe frame, dimensions approximately 38 x 46 cm, comprised of six crossbars connected by eight tee fittings and four 90° elbows. One 41 x 64 cm sheet of air conditioning filter material was folded over each crossbar and fixed with plastic cable ties, resulting in 12 total pages. Air trapped within the sealed PVC frame provided flotation. Collectors were anchored at sea by 1 cm (3/8 in) polyethylene trap line spliced with a rubber hose chafe guard to a single concrete building block, tied to the collector with a bowline knot followed by a half hitch. Including shipping costs of the air conditioning filter material, approximate cost per collector in Antigua was $35.00 (U.S.).

General Sample Design and Study Sites

An unbiased index of recruitment requires a random component to the sample design. Thirteen nearshore sites were selected around the coast of Antigua by using random numbers to represent distances between sites (2.4 km per random number unit on a chart of scale 1:50,000). Fifteen additional sites, consisting of nine nearshore and six offshore locations (0.6 to 4.8 km from shore), were selected nonrandomly to increase the variety of habitats and areal

coverage of the sample. Figure 1 shows the locations and designations (random or nonrandom) of the 28 collector sites maintained throughout the study.

Logistics and Sampling Protocol

Three full sea days per week were required to sample all 28 sites, with each collector sampled once per seven days. Sampling was executed by two persons in a 5.5 m (18 ft) open native fishing vessel of heavy wood construction, powered by a 25 hp outboard motor, and equipped with a high volume hand bilge pump for use in heavy sea conditions. Total travel distance between collectors was 70 km (43.5 mi). A secchi disk, thermometer, and refractometer were used to record turbidity, temperature, and salinity at each site. A fine mesh (4 mm) net sewn on a 0.8 x 1 m PVC frame was used to dip net collectors before untying and bringing them aboard for examination. Both sides of each page in the collector were searched, in sequence, two times; the exterior of the collector was then examined from all angles, after which the collector was lifted and given several brisk shakes over the net positioned in the bilge of the boat. Pueruli were counted and classified according to five degrees of pigmentation; other postlarvae were classified as either recent first post-pueruli or juveniles (Figure 2). Number and position of missing and damaged pages were noted for each collector prior to repairs. Average wind speed and average cloud cover were estimated for each sample day. All data were recorded with pencil on underwater paper in the field and recopied onto standardized forms each week.

GENERAL RESULTS

Table 1 lists number, name, habitat classification, bottom type, depth, distance from shore, and total number of postlarvae collected for the year at each of the study sites depicted in Figure 1. Two nearshore sites located on the windward (east) coast, Flat Point and Indian Creek, were most productive, followed by a third nearshore site, Belfast Bay (Table 1, Figure 1). Two offshore sites, Diamond Tower (4.8 km from the northwestern shore) and Cade Reef (1.6 km from the southwestern shore), produced nearly the same total number of postlarvae as Belfast Bay (Table 1, Figure 1).

Figure 3 shows the mean number of postlarval lobsters per collector per weekly sample for 49 consecutive weeks beginning 28 August 1987 and ending 29 July 1988. Dates of new moon phases are denoted by solid circles positioned above the horizontal axis. Peak recruitment occurred during the new moon and first quarter of all months sampled.

Exceptionally high recruitment occurred during the months of February and May, with the latter month exceeding the recruitment of all other months. These pulses of recruitment coincided with strong southwesterly currents measured by a swordfish longline vessel 19 to 32 km east of Antigua, an area where the current usually sets in northerly directions.

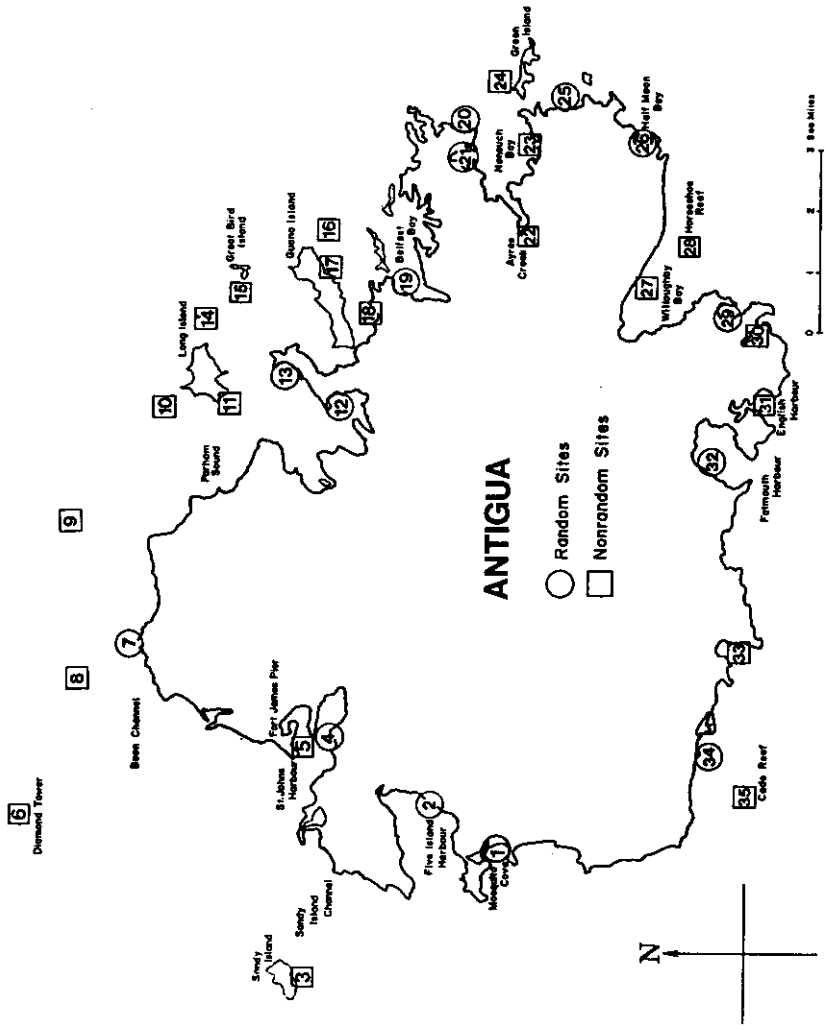

Figure 1. Locations of the 28 collectors maintained for a period of 49 weeks between August 1987 and July 1988 in coastal waters 1m to 4.8 km from shore around Antigua. Circled numbers indicate random sites. Squares indicate nonrandom sites.

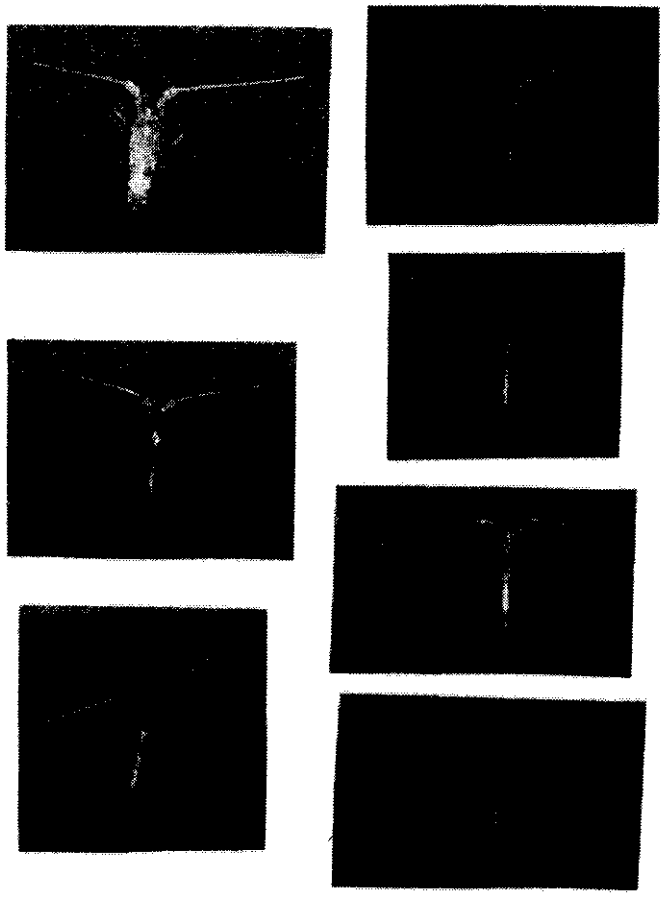

Figure 2. Classifications of postlarval lobsters: Stage I (top left) - clear, newly arrived puerulus exhibiting no pigment; Stage II (middle left) - puerulus with slight pigmentation at base of antennae and sometimes faint pigment along sides of carapace; Stage III (bottom left) - pigmentation darker at base of antennae, clearly visible along sides of carapace and tail, banding on legs darker than Stage II; Stage IV (top right) - pigmented areas darkened and expanded dorsally, distinct pigmentation of uropods and telson; Stage V (second from top, right) - uropods, telson, carapace, and tail section darkly pigmented; Stage VI (third from top, right) - first post-puerulus molt, carapace now more cylindrical; Stage VII (bottom right) - light dorsal stripe disappearing, tail section elongated, uropods enlarged.

Table 1. Number, name, habitat classification, bottom type, depth (m), distance from shore (km, or * denoting less than 50 m) and total number of postlarval lobsters collected for 28 study sites around Antigua over 49 weekly samples between 28 August 1987 and 29 July 1988. Habitat classifications are: 1 = mangrove, 2 = rocky shore, 3 = mixed mangrove/rocky shore, 4 = inshore reef, 5 = offshore reef. Bottom types are: 1 = mud, 2 = sand, 3 = *Thalassia*, 4 = rock, 5 = hardground, 6 = hardground/*Thalassia*, 7 = sand/*Thalassia*, 8 = coral/coral rubble, and 9 = sand/coral rubble.

COLLECTOR NO.	NAME OF SITE	HABITAT CODE	BOTTOM CODE	DIST. DEPTH (m)	TOTAL FROM SHORE	NO. INDIV.
1	Mosquito Cove	3	3	2.6	*	398
2	Five Island Harbour	2	3	2.1	*	92
4	St. John's Harbour	2	1	2.4	*	209
6	Diamond Tower	5	8	3.4	4.8	870
7	Boon Point	4	9	0.8	*	253
8	Northwest Reef	5	9	3.4	1.9	427
9	Horseshow Reef	5	8	3.3	2.4	194
10	Long Island North	5	8	2.6	0.8	271
11	Long Island South	1	3	1.3	*	68
12	Parham Harbour	1	3	1.1	*	124
13	Crabbs Peninsula	1	3	1.2	*	91
15	Great Bird Island	4	9	3.0	*	41
16	Guana Reef	3	7	2.0	0.6	363
17	Guana Island	3	7	2.0	*	453
18	Guana Bay	1	3	2.6	*	170
19	Belfast Bay	3	6	2.0	*	974
20	Flat Point	3	6	1.1	*	1800
21	Ledcoff Cove	1	3	3.0	*	39
23	Nanny Island	3	6	1.8	*	592
24	Bird Island Reef	5	2	3.3	*	478

Table 1. Continued.

COLLECTOR NO.	NAME OF SITE	HABITAT CODE	BOTTOM CODE	DIST. DEPTH (m)	TOTAL FROM SHORE	NO. INDIV.
25	Devil's Hole Island	4	9	5.3	*	451
27	Willoughby Bay	3	6	1.2	*	231
29	Mamora Bay	2	7	3.0	*	348
30	Indian Creek	1	1	2.3	*	1712
32	Falmouth Harbour	2	3	2.3	*	80
33	Carlisle Bay	2	7	3.0	*	25
34	Cade Bay	4	6	1.8	*	168
35	Cade Reef	5	9	2.2	1.6	775

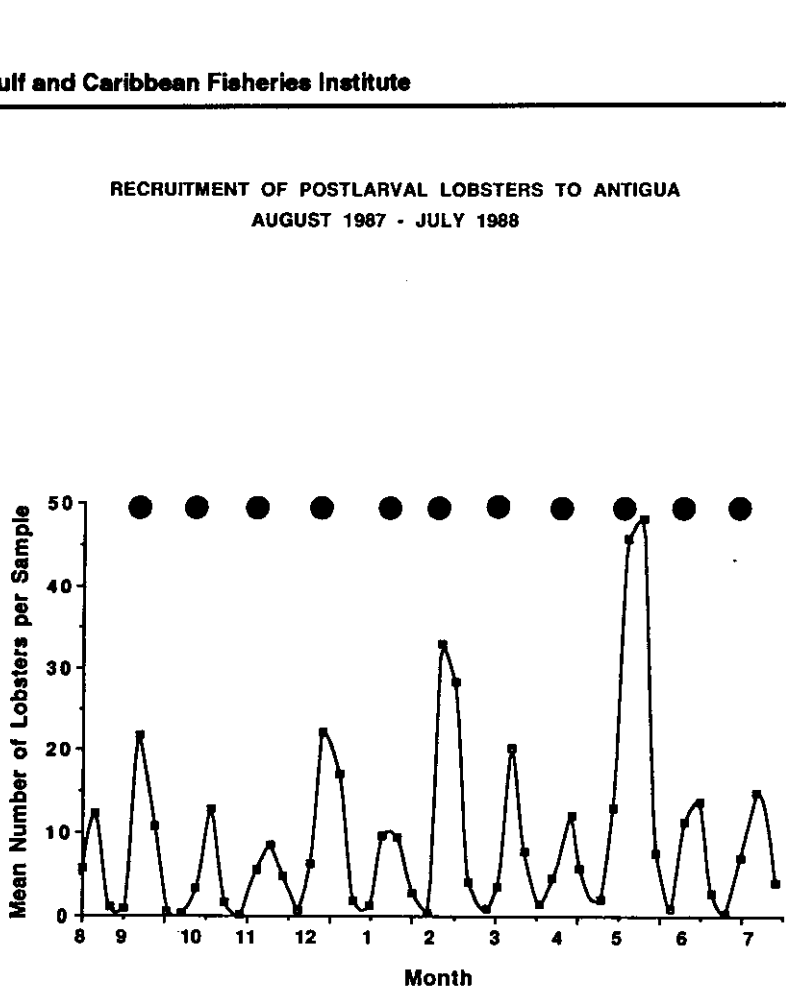

Figure 3. Mean number of postlarval lobsters per weekly sample for all 28 collectors combined. Date of new moon phases are denoted by solid circles positioned above the horizontal axis. Time scale begins August 1987 and ends July 1988.

A full analysis of all of these data is under way and will be published in separate manuscripts. The analysis includes multivariate testing for explanation of variation in catch of postlarvae per site by moon phase, season, coast, habitat, and bottom type, and correlations of catch with physical parameters including temperature, salinity, and general wind and current conditions. Results of a 24 week controlled field experiment, involving arrays of 13 collectors at each of two sites (Belfast Bay and Flat Point) and designed to determine the effect of

distance between collectors and sampling frequency on catch per collector, will also be reported separately.

DISCUSSION

We have described the specific research objectives, general approach, sample design, methods, equipment and materials, required personnel and effort, and general results of our assessment of postlarval lobster recruitment in Antigua. We will discuss in this section the cost of a program of this scale in the eastern Caribbean and compare it to the benefits derived in terms of information return and potential practical applications of this information.

Cost of Assessment

Table 2 summarized the costs of a large-scale, one year assessment in Antigua, starting with nothing. Values are in some cases actual expenditures of our program, in other cases, estimates based on local knowledge obtained during the course of the study. All items listed are available locally with the exception of the air conditioning filter material, which had to be shipped from the U.S.

Table 2 shows total cost of assessment to be approximately $71,618, not including transportation of an employee from the U.S. to Antigua (or other potential location). This figure is representative of the cost of a similar-scale assessment in the eastern Caribbean region, with slight adjustment for shipping where certain materials may be unavailable locally. Similarly, cost of housing might differ somewhat depending on the country. Where an assessment was initiated by an existing entity, such as a government fisheries department, the cost would likely be considerably less.

Return on Investment

For our approximately $75,000 (U.S.) expenditure, we obtained a sample size of 11,697 postlarval lobsters from the 28 collector sites (Table 2). This sample is sufficient to provide the most detailed, largest-scale picture published to date on magnitude, periodicity, and spatial distribution of lobster recruitment over a one year period in the tropical western Atlantic. Including additional field experiments conducted during the study, total sample size was approximately 22,817.

Despite the biological insights provided by this and other studies, the information has no immediate application when viewed strictly from the perspective of fisheries management unless:

1. a complementary set of data exists on either harvest of adult age groups or fishery-independent estimates of adult population size; or
2. the study is part of a coordinated, region-wide effort that includes electrophoretic analyses of statistically sufficient samples to enable

Table 2. Summary of one year assessment of postlarval spiny lobster recruitment in Antigua.

CAPITAL COSTS – COLLECTING EQUIPMENT	**$7,260**
Native fishing vessel - 5.5 m	$1,880
outboard motor - 25 hp	3,000
fuel tanks - three 6 g plastic tanks	180
50 collectors	1,750
collector net	20
refractometer	240
thermometer	25
secchi disk (home made)	10
emergency tool kit	45
dive gear	110
PERSONNEL SALARIES (2)	**$45,000**
MAINTENANCE/OPERATING	**$4,858**
boat gas - 28 g/ 233k @ $2.00/g for 50 weeks	$2,800
outboard oil – $1.20/16 oz., 90oz./week	300
air conditioning filter material for 50 weeks	
collector maintenance – 20 rolls	700
shipping	300
cable ties - for maintenance	100
rope – 600 ft	58
oatboard and boat maintenace	500
underwater paper, pencils, misc. supplies	100
TRANSPORTATION/HOUSING	**$8,900**
vehicle– small used pickup truck	$3,000
gasoline - 15 g /week @ $2.00/g, 50 weeks	1,500
house - including utilities, $300/mo, 12 mo	3,600
vehicle maintenace	800
OFFICE	**$5,600**
personal computer - with printer, software	$5,000
computer supplies and service	500
office supplies	100

definition of unit stocks.

This brings us to the question of how limited resources should be allocated.

If one were to devise a preference schedule for collection of data for a small nation with limited funds that would maximize information necessary for conservation and management of economically valuable fishery resources, a study of pueruli settlement would probably not be included on the list. Procurement of representative length frequency samples from the commercial catch for a one year period, for example, would be much more cogent to determining population status. Age and growth studies and efforts to obtain data on annual total catch in numbers and total annual effort stratified by area, depth, and gear should all take precedence over a recruitment study. Furthermore, fishery-independent adult stock assessments are at least as important as a study of recruitment.

Quantitative, collector-based studies of postlarval lobster recruitment can, however, serve practical fishery management purposes. First, where time-areal coverage of collectors and sample size is sufficient and adult stock population estimates exist, stock recruitment relationships can be estimated (see Morgan *et al.*, 1982). If such a general relationship can be clearly demonstrated, which is usually not the case for marine fishery resources, it can have direct value as a management tool. Second, again with adequate sampling coupled with at least catch data, a correlation between recruitment of pueruli and catches of age groups recently recruited to the fishery may allow prediction of future catches (Phillips, 1986). This could be invaluable to resource management and could more than pay for itself when compared to revenues lost to the private sector through overcapitalization and overfishing.

Time-area coverage and size of our sample from Antigua is likely sufficient for correlation with commercial catch, if appropriate data on catch existed. This returns us, however, to the question of a preference schedule for data collection in the absence of information. Most other eastern Caribbean islands, like Antigua, have little or no significant catch and effort data for correlation with the recruitment data that could be obtained from collectors. Further, collection of appropriate data is not imminent. This means that funding should be sufficient for both catch and effort data collection and a collector-based recruitment study; otherwise, any available resources should be allocated for collection of more cost effective fishery data (beginning with representative length frequency sampling, which yields the most information on population status for the least cost and effort).

Another potential application of a collector-based recruitment study, beyond traditional fishery management, is retention of sampled postlarvae for grow-out to market size. Part of our recruitment assessment program involved support of a U.S.A.I.D.-funded extensive aquaculture experiment to test this application.

Over 90% of approximately 15,000 individuals tested survived transport from field to laboratory in oxygen-filled plastic bags with a small amount of habitat and seawater. Subsequent mortality due to stress of transport or other causes at the holding facility, costs, and other parameters affecting feasibility of mass rearing in Antigua had not been determined, however, by the end of the study period. Further testing of this application would require a considerable investment of time and money with no guarantee of success. An integrated approach, perhaps in conjunction with a poultry or hog farm to reduce costs by feeding offal to lobsters, might someday succeed. This level of cost and risk, though, is not normally within the purview of the government of a developing country.

The primary return on an investment in a large-scale recruitment study similar to the one described in this paper, in the absence of concurrent catch data or a viable commercial lobster farm, is a contribution to the knowledge of aspects of the biology and ecology of a commercially important resource. This is not without potential value for fishery management or extensive aquaculture prospects. The large sample size and temporal-spatial detail of the data lend themselves to critical considerations for aquaculture, such as assessment of optimal production strategies and mitigation of impact of high magnitude collecting on future populations of locally exploited adults. Results can be compared to other studies in the region and possibly provide insights on stock definition. The individuals sampled can provide material for electrophoretic studies, also designed to determine origins and degree of interchange between different exploited populations. A study of this kind has obvious and direct implications for regional management.

Even in isolation, the assessment can provide detailed ecological information relevant to the study area. Herrnkind *et al.* (1988), for example, imply that heavy siltation may negatively impact settlement of pueruli. Data on settlement rates in different sites around an island might therefore be useful for selection of development zones that would have the least impact on recruitment of lobsters.

CONCLUSIONS AND RECOMMENDATIONS

We have shown the feasibility of a large-scale lobster recruitment assessment in the eastern Caribbean in terms of attainable objectives, sample design, methods and protocol, costs and logistics, and potential applications of results. We conclude with several practical recommendations based on our experience:

1. **Collector construction** – we felt that avoiding the use of styrofoam floats and unnecessary hardware reduced the inevitable losses of collectors to theft and vandalism. Closed-frame construction provided

adequate flotation, and although we lost information occasionally when a collector sank from seal failure, the loss was more than compensated by reduced theft.

2. **Sample design** – maximization of areal coverage by the available number of collectors is essential to obtaining a representative sample of recruitment. Concentration of collectors in a small number of areas could easily provide a misleading picture of relative abundance of recruits due to the patchy distribution of arriving postlarvae.
3. **Data collection** – we strongly recommend categorization of samples according to the seven postlarval stages presented in this paper. The ability to back-calculate estimated arrival time of pueruli is a valuable asset to the program. Also, placement of a fine mesh (approximately 4 mm) net under the collector prior to removal from the sea is important. Especially during periods of high recruitment, large numbers of individuals (as many as 30 in one case) could be lost from the sample. Of the physical parameters recorded, we found that offshore drift vectors obtained from fishing vessels and other notes on prevailing wind and weather conditions have the most potential for explaining variation in recruitment other than lunar phase.
4. **Sampling vessel** – a heavily constructed displacement hull, similar to designs of small fishing vessels found throughout the eastern Caribbean, enabled us to sample both nearshore and offshore sites for 49 consecutive weeks in often heavy wind and sea conditions. Most similar-sized "modern" planning hull designs would have cost more initially, required more fuel, and in any event would almost certainly not have survived the conditions.
5. **Personnel and purchasing** – maximum interaction with the local economy is highly recommended. It can result in considerable savings to the program if executed properly. Even if initial costs are somewhat higher than duty-free importation, the benefit of community involvement and support cannot be overestimated. Hiring of research assistants from the local population whenever possible is strongly advised. Collectors are vulnerable to removal, and we felt that good public relations played a key role in our ability to obtain a continuous one year sample.
6. **Data management** – we recommend recording data in the field on pre-coded, entry-ready sheets exactly as it will be typed on the computer and a sampling schedule that permits weekly data entry and at least monthly computation of descriptive statistics summaries. Use of underwater paper in a copying machine will provide waterproof field sheets.

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