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Sampling larval fishes with a nightlight lift-net in tropical inshore waters

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Abstract

The applicability of a nightlight lift-net for sampling ichthyoplankton assemblages was evaluated in inshore habitats off southwestern Puerto Rico. The effects of lunar periodicity, habitat, light duration, and gear type (nightlight vs. plankton tow) were investigated. Overall, 36 piscine taxa were collected with the nightlight lift-net from inshore habitats (i.e. coral reef, mangroves, seagrass bed, sand flat). Larval fishes (80.6%), particularly clupeids (*Jenkinsia* spp. and *Harengula* spp.), were the predominant developmental stage collected. Juvenile and adult fishes accounted for 14.7% and 4.7% of the catch, respectively. Nightlight collections showed marked patterns in larval fish abundance during different lunar phases with peak catchability occurring during the new moon phase. New moon samples accounted for 65.7% of all larvae collected during the complete lunar cycle. Significant lunar effects were observed in coral reef, seagrass bed, and sand flat habitats. No lunar related trends were observed in mangrove cay or nearshore mangrove habitats. Spatial patterns in nightlight catches were present with many taxa showing significant differences in abundance among habitats sampled. During lunar periodicity trials, catches were highest in the seagrass bed and coral reef habitats. Taxonomic diversity was greatest in seagrass bed and coral reef habitats with 16 and 11 taxa, respectively. Low abundance and taxonomic diversity characterized mangrove cay and nearshore mangrove habitats; however, increases in taxonomic diversity were observed during a fall survey of nearshore mangrove habitats. Light duration experiments indicated that larval abundance increased with increasing sampling duration and maximum catch per unit time was obtained at 10 min. Longer and shorter durations resulted in lower catch per unit effort and greater coefficients of variation. Trends in species composition and development stage were detected among nightlight lift-net and plankton net-tow methods.

Keywords: Larval fishes; Recruitment; Light traps; Coral reefs; Mangroves; Seagrass beds; Lunar periodicity

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1. Introduction

Processes occurring during the early life history of tropical marine fishes are important determinants of size and composition of adult assemblages (Doherty, 1981; Sale, 1988; Doherty and Williams, 1988). Local population size may be strongly influenced or possibly determined by pelagic stage mortality (Robertson, 1988; Doherty and Williams, 1988). In addition, physical processes (i.e. currents) affect larval fish dispersion which can have significant demographic consequences for many species (Miller, 1974; Bakun, 1986; Richards and Lindeman, 1987; Black et al., 1990). Furthermore, behavioral interactions (i.e. competition and predation) among residents and newly recruited larvae may modify patterns present in adult reef fish assemblages (Shulman et al., 1983; Doherty and Sale, 1985; Jones, 1990; Hixon, 1991). For these reasons, the early life history of tropical marine fishes has received widespread attention over the past decade, particularly aspects of larval dispersal and recruitment.

Because of their potential as nursery sites for larval fishes, tropical inshore habitats such as fringing reefs, mangroves, and sea grass beds, are of particular interest to fisheries ecologists. However, complex bathymetry and spatial heterogeneity present in these habitats leads to inherent sampling problems and thus limits the use of conventional plankton sampling methods (e.g. plankton net tows). As a result, alternative collection methods have been developed to sample larval fishes in such habitats, including diver-towed nets (Emery, 1968; Smith et al., 1987), purse-seines (Murphy and Clutter, 1972; Kingsford and Choat, 1985; Kingsford et al., 1991), pumps (Yocum et al., 1978; Brander and Thompson, 1989) and light aggregation-devices (Doherty, 1987; Brogan, 1994).

A method receiving considerable attention in recent years is the use of light at night (nightlighting) to aggregate larval fishes for capture. Nightlight collection can be accomplished using pumps (Bullis and Roithmayr, 1971), nets (Sale et al., 1976; Smith et al., 1987; Dennis et al., 1991), and traps (Doherty, 1987; Riley and Holt, 1993; Brogan, 1994). Although devices differ in design, all are based on the premise that certain fish larvae are photopositive and nightlighting serves to concentrate them for collection. Nightlighting has several advantages over conventional methods for sampling in nearshore habitats. Gear can be placed in shallow water microhabitats (< 1 m) with non-uniform bottom topography (i.e. patch reefs) and the method is less destructive than conventional plankton net tows, particularly in highly sensitive areas (i.e. coral reefs). Nightlighting can also collect larvae which are in close association with the seabed and normally inaccessible by alternative methods. In addition, nightlighting is an effective means of collecting larger larvae that can avoid towed nets (Doherty, 1987; Leis, 1991).

The purpose of this study was to test the applicability of a simple, inexpensive (about $120 US) nightlight lift-net technique for sampling larval fishes in inshore habitats. An improved understanding of methodological considerations, not addressed in earlier nightlight research by Dennis et al. (1991), was the primary aim of this study. The effectiveness of this method on catch composition and size was evaluated under a variety of physical and environmental conditions including lunar periodicity, habitat (e.g. coral reef, mangroves, sand flat, and seagrass bed), and light duration. Also, the nightlight lift-net technique was compared with conventional plankton net tows. Findings from this study will enhance our

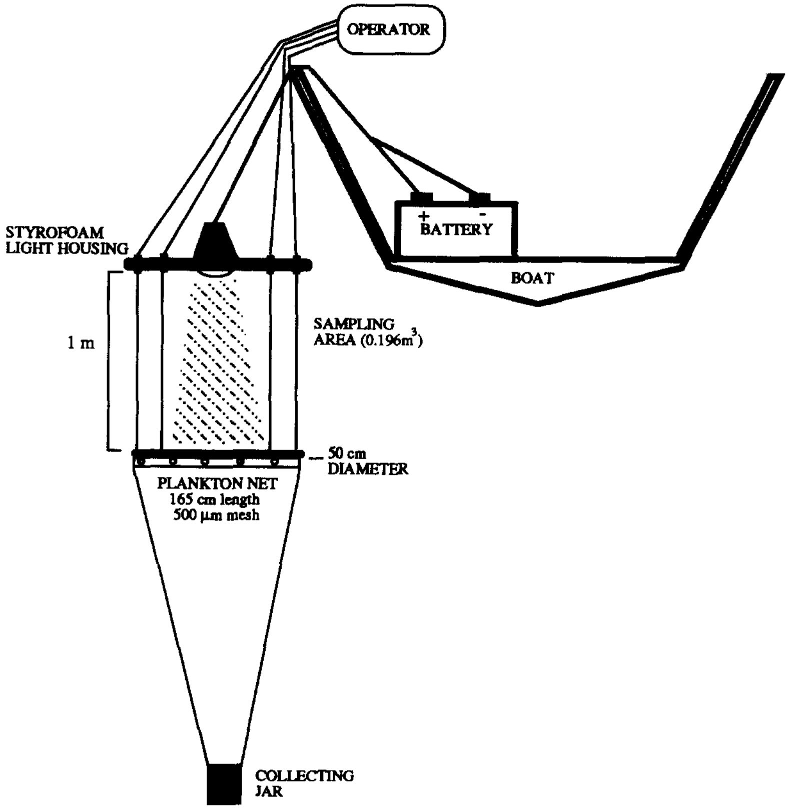

Fig. 1. Schematic representation of the nightlight lift-net.

present understanding of nightlight sampling performance and should prove valuable to researchers attempting to design larval fish sampling protocols for tropical inshore habitats.

2. Materials and methods

2.1. Nightlight lift-net design

The nightlight lift-net consisted of a floating light platform constructed of a circular piece of Styrofoam, 65 cm diameter (Fig. 1). At the center, a 12 V headlight bulb was positioned such that the convex surface of the bulb was protruding beyond the surface of the Styrofoam platform. The bulb was fixed into position with clear silicon sealant and housed within a plastic shield to protect the contacts from sea water. The bulb was powered by a 12 V marine battery on board a 6 m outboard motorboat. Four holes were bored into the Styrofoam platform and each hole was lined by an 8.0 cm length of 1.5 cm diameter PVC tubing. Lines were placed through the guide holes and attached to a steel ring (50 cm diameter) of an 165 cm long plankton net with a 500 μm mesh size. The cod end contained a 1 l glass jar that served as the sample container.

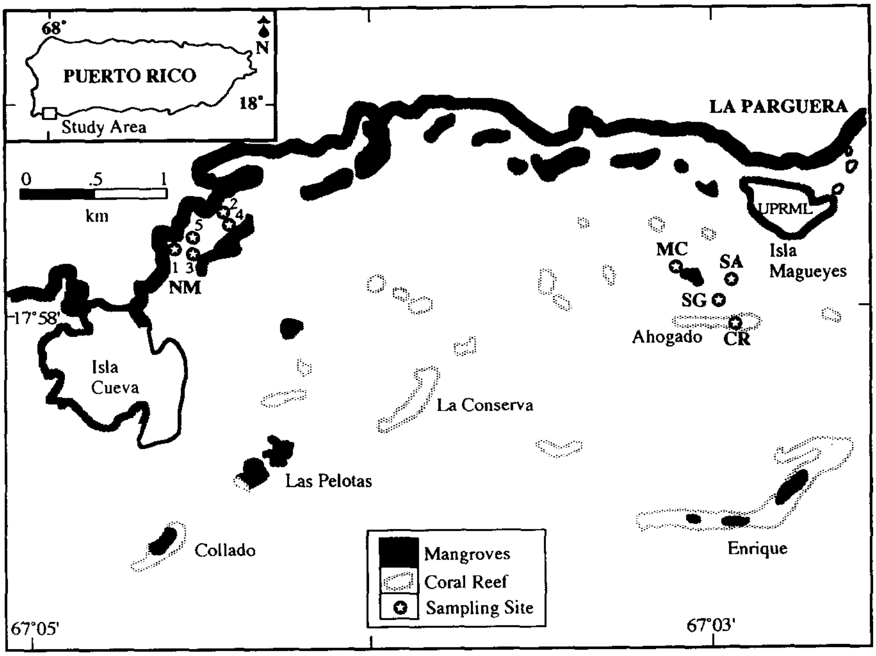

Fig. 2. Location of the study area in southwestern Puerto Rico illustrating the sampling sites investigated (Ahogado: CR, coral reef; SA, sand; SG, seagrass bed; MC, mangrove cay. Nearshore mangroves (NM): 1–4, mangrove prop-roots; 5, mangrove lagoon).

2.2. Study area

Ichthyoplankton was sampled from a variety of inshore habitats off southwestern Puerto Rico. Coral reef, mangrove cay, sand bottom, and seagrass bed habitats were sampled near a patch reef (Ahogado) situated 1.0 km southwest of the University of Puerto Rico Marine Laboratory (UPRML) (Fig. 2). The coral reef station was located on the leeward edge of Ahogado, a semi-emergent patch reef dominated by stands of elkhorn coral (*Acropora palmata*). Water depth was approximately 1.0 m and the adjacent bottom was covered with turtle grass (*Thalassia testudinum*). The seagrass bed station was located 50 m north of Ahogado and composed primarily of *Thalassia testudinum*. Water depth averaged 1.5 m. Approximately 150 m north of Ahogado was the sandy bottom site, with sediments composed mainly of carbonate sand of reef origin at a depth of 1.7 m. The mangrove cay prop-root station was situated on the leeward side of an inshore mangrove cay 0.5 km north of Ahogado. Five additional nearshore mangrove stations were also sampled in this study. These stations consisted of four mangrove prop-root sites and one mangrove lagoon site located in the channel separating mangrove island stations from shoreline mangrove stations. Nearshore mangrove sites were approximately 3.5 km west of UPRML. Mangrove stations were dominated by red mangroves (*Rhizophora mangle*) and depth ranged from 1.2 to 1.7 m. Bottom sediments at mangrove stations were predominately silt-sized particles. All sites, including mangrove locales, were characterized by oceanic water conditions throughout the duration of this study. Salinity remained high (34–37‰) year-round and water clarity was relatively good (visibility greater than 5 m). Visibility estimates, based on diver observations, varied little among sites (nearshore mangroves, about 3–5 m; coral reef, mangrove cay, seagrass and sand habitats, 5–7 m) and no differences were observed among seasons. Wind was generally negligible during nocturnal sampling periods.

2.3. Sampling design

Sites located in the vicinity of Ahogado were sampled during summer months (June–July 1987) while nearshore mangrove sites were sampled during fall (September–November 1987). At Ahogado, all four habitats were sampled sequentially once per week for an entire lunar month. Collections were made at each location on the same night. Two nearshore mangrove stations (lagoon and prop-root) were also sampled at weekly intervals over an entire lunar cycle; however, the reduced number of sampling sites provided sufficient time for multiple collections (three replicates per lunar phase per habitat) on the same night. Nearshore mangrove prop-root and lagoon sites were alternately sampled. The order of nightly collections among habitats during summer and fall collections was randomly selected. Sampling was conducted between 21:00 and 24:00 h on all dates. A typical sampling period consisted of lowering the plankton net into the water at a depth of 1.0 m after which the light was turned on. At the end of the sampling period, the net was lifted rapidly to the surface, with the light still on. All fish present in the water column beneath the light to 1.0 m depth were sampled, except those avoiding the vertically towed net. Based on net diameter and length, the volume of illuminated water sampled during each lift-net sample was 0.196 m^3($\pi r^2 h$) with altitude, h, being the perpendicular distance between the Styrofoam light housing and plankton net ring.

Lunar periodicity and light duration were examined to determine the effect of light-related variations on catch composition and size. Lunar periodicity was examined by collecting samples during the four major lunar phases: new, first quarter, full, and last quarter. Lunar effect was investigated during the summer at Ahogado reef (June–July 1987) and two nearshore mangrove stations were sampled in the fall (October–November 1987). The effect of variable sampling duration was also tested at the sand bottom station at Ahogado reef on 3 days surrounding the new moon in July 1987. Replicate samples were taken for each of six different light durations: 0 (no light), 1, 2, 5, 10, 20 min. The order of sampling periods for duration experiments was selected randomly with a 10 min period of no light between samples. Since no declines in numbers were detected among consecutive replicates, 10 min no light periods seemed adequate to allow for recovery. Three replicates were taken during each lunar phase and light duration trial.

To further investigate ichthyofaunal composition of nearshore mangrove habitats, night-light lift-net collections were also taken from the four nearshore mangrove stations over a 3 month period (September–November 1987). Replicate samples were collected monthly during the new moon lunar period. Collection sequence among the four mangrove habitats was random.

A comparison between a conventional plankton net and the nightlight lift-net was conducted in a lagoon adjacent to the mangrove island station during July 1987. A plankton net, of the same dimensions as the lift-net, was towed behind a 6 m outboard motorboat at a speed of 0.55 m s^{-1} (2 km h^{-1}). The net was towed for a period of 10 min on a course perpendicular to the direction of wind. Nightlight lift-net samples were collected from the same area in the manner described above. Methods were alternated during trials and three replicates of each were taken. Physical constraints precluded the use of net tows in other habitats and therefore, limited the scope of inshore comparisons among methods. All organisms collected were preserved in 10% buffered formalin in the field. In the laboratory, ichthyofauna in the samples was identified to lowest possible taxonomic category. Due to the lack of descriptive keys, some engraulid and gobiid species were only identified to the family level. Distinct species from these families, apart from taxa with positive identifications, were coded numerically (e.g. Engraulid Species 1, 2, and 3). Standard length and life history stage (preflexion, postflexion, juvenile, adult) were recorded. Specimens were later placed in 70% ethanol for long-term storage.

Due to inherent biases associated with light-aggregating techniques (e.g. unknown sampling volume, taxonomic selectivity of gear), absolute densities of larvae and small pelagic fishes could not be determined for nightlight collections. As a result, our estimates of abundance are relative and based on the number of individuals per sample (i.e. catch).

2.4. Statistical treatments

The effects of lunar periodicity and habitat on catches were analyzed with a chi-square "goodness of fit" test (Sokal and Rohlf, 1981). Low abundances were obtained in many samples and, as a result, more sophisticated statistical analyses could not be employed. Regression analysis was used to evaluate the effect of light duration on catch size. The statistical software package SYSTAT was used for statistical analyses (Wilkinson, 1989).

3. Results

3.1. Catch composition

Overall, 36 taxa were collected from inshore habitats off southwestern Puerto Rico with the nightlight lift-net. Table 1 summarizes nightlight lift-net collection data for the three primary sampling phases of this study: lunar periodicity (A), light duration (B), and fall nearshore mangrove prop-root survey (C). Baitfishes, particularly clupeoids, dominated nightlight collections in all sampling phases and habitats. The most abundant taxa collected were clupeids (*Jenkinsia* spp. and *Harengula* spp.) and engraulids (*Anchoa* spp.). *Jenkinsia* spp. alone accounted for 56% of all fish collected and dominated the shallow water reef ecosystem at Ahogado (i.e. coral reef, seagrass bed, and sand stations). By contrast, nearshore mangrove collections were composed primarily of *Harengula* spp. and *Albula vulpes*.

Nightlight lift-net collections showed a strong bias toward early life history stages of fishes. Collections were dominated by larval fishes (80.6%), particularly post-flexion stage larvae (91.0% of total larvae). Juvenile and adult fishes accounted for 14.7% and 4.7% of the total catch, respectively.

3.2. Lunar periodicity

Nightlight collections showed marked patterns in larval fish abundance during different lunar phases for all habitats combined ($\chi^2 = 642.20$, d.f. = 3, $P < 0.01$; Table 2). For summer collections at Ahogado, chi-square analysis showed that catches were significantly higher during the new moon ($\chi^2 = 723.51$, d.f. = 3, $P < 0.01$). New moon samples accounted for 71.6% of all larvae collected during the complete lunar cycle at Ahogado. Abundance during the new moon was four-fold higher than the next most abundant phase, last quarter. Catches were lowest during the full moon with more than a ten-fold reduction from new moon values. Moderate catches were obtained for last and first quarter phases. No significant lunar effect on larva abundance was observed during fall collections in nearshore mangrove habitats ($\chi^2 = 7.43$, d.f. = 3, $P > 0.05$). Significant interaction between lunar phase and habitat was also present during the summer ($\chi^2 = 366.26$, d.f. = 9, $P < 0.01$). Coral reef and seagrass habitats showed patterns similar to the general trend described above with larva abundance highest during the new moon phase. By contrast, catches at sandy bottom and mangrove cay stations did not reflect this pattern. In fact, larva abundance at the sandy bottom station was highest during the last quarter moon phase. No lunar pattern in abundance was evident at the mangrove cay station ($\chi^2 = 2.17$, d.f. = 3, $P > 0.05$). Similarly, fall collections from nearshore mangrove habitats showed no significant lunar effects (prop-roots: $\chi^2 = 2.38$, d.f. = 3, $P > 0.05$; lagoon: $\chi^2 = 6.43$, d.f. = 3, $P > 0.05$).

Relative abundance of different developmental stages also varied with lunar phase ($\chi^2 = 309.17$, d.f. = 9, $P < 0.01$). Juvenile and adult stage fishes, unlike larvae, were not caught in peak numbers during the new moon phase. Juveniles were significantly more abundant during the last quarter and full moon. By contrast, adults showed highest and lowest levels of catchability during the first quarter and new moon, respectively. In both cases, lunar effects were statistically significant (juveniles: $\chi^2 = 40.83$, d.f. = 3, $P < 0.01$; adults: $\chi^2 = 10.00$, d.f. = 3, $P < 0.05$).

3.3. Habitat effect

Habitat effect on nightlight lift-net collections was investigated during both lunar periodicity trials at Ahogado and a nearshore mangrove survey conducted in the fall (September–November) during new moon periods. Chi-square results from lunar periodicity trials at Ahogado (June–July) indicated that habitat (i.e. coral reef, seagrass, sandy bottom, and mangrove cay) had a significant effect on the number of larval and total fish collected per sample ($\chi^2 = 480.86$, d.f. = 3, $P < 0.01$ and $\chi^2 = 421.05$, d.f. = 3, $P < 0.01$, respectively). Chi-square analysis was also performed individually on the three most abundant taxa from these collections (*Harengula* spp., *Jenkinsia* spp., and Engraulidae) and significant ($P < 0.05$) results were present for each taxa. Coral reefs showed the highest catches accounting for over 44% of all fish collected. For the remaining habitats, ichthyofaunal abundance decreased in the following order: seagrass bed, sand bottom, nearshore mangroves and mangrove cay. The most species-rich habitats were sandy bottom and coral reef with 16 and 11 taxa, respectively. Species diversity was lowest at the mangrove cay station (four taxa). Fall ichthyoplankton collections taken during lunar periodicity trials in near-

Table 1

A comparison of taxa (all developmental stages) collected with the nightlight lift-net in nearshore habitats off southwestern Puerto Rico for three different sampling phases (A, B, and C): A represents collection data from lunar periodicity trials (summed over all moon phases at Ahogado and nearshore mangroves); B represents collection data from light duration experimentation (summed over all light durations); C represents collection data from a fall survey of nearshore mangrove prop-root habitats (new moon collections summed over 3 months, September – October). Figures in parentheses denote the number of unidentified taxa

Taxa	A						B	C			
	Ahogado				Nearshore mangroves		Ahogado	Nearshore mangroves			
							Sand	Prop-root stations			
	Coral reef	Seagrass bed	Sand	Mangrove cay	Prop-root Station 4	Lagoon Station 5		1	2	3	4
ALBULIDAE											
Albula vulpes	–	–	2	–	4	4	26	35	47	36	49
ATHERINIDAE	8	2	1	–	1	1	38	4	3	–	1
Atherinomorus stipes	1	1	1	2	2	5	4	11	3	–	9
Hypoatherina harringtonensis	–	–	3	1	–	–	6	–	–	–	–
BOTHIDAE	–	–	–	–	–	–	–	1	1	1	–
CLUPEIDAE											
Harengula spp.	7	23	8	2	49	65	40	24	37	39	52
Jenkinsia spp.	401	170	79	27	2	10	768	–	–	–	–
Opisthonema oglinum	3	–	8	–	–	–	3	–	1	–	–
ELOPIDAE											
Elops saurus	–	–	–	–	–	–	–	–	4	–	–
ENGRAULIDAE											
Anchoa lyolepis	6	4	4	–	9	3	35	2	2	2	3
Species 1	–	–	1	–	–	1	–	–	–	–	–
Species 2	–	9	29	–	–	–	156	2	6	11	5
Species 3	–	–	1	–	–	–	–	–	–	–	–
GERREIDAE	–	–	–	–	2	1	–	17	25	17	12
GOBIIDAE	–	–	1	–	–	–	3	–	–	–	–
Species 1	–	–	–	–	–	–	–	2	11	6	–
Species 2	–	–	–	–	–	–	–	7	1	6	2
HAEMULIDAE	2	–	–	–	–	–	–	–	–	1	–
EXOCOETIDAE											
Hemiramphus sp.	–	–	–	–	–	–	–	–	1	–	–
LABRIDAE	–	–	–	–	–	–	–	–	–	1	–
LUTJANIDAE	–	–	–	–	–	–	–	–	–	2	1
MUGILIDAE											
Mugil sp.	–	–	–	–	–	–	2	–	–	–	–
OPHICHTHIDAE											
Myrophis platyrhynchus	–	–	1	–	–	–	–	–	–	–	1
POMACENTRIDAE	–	–	–	–	1	1	–	–	4	–	–
SOLEIDAE	–	–	–	–	–	–	–	1	1	–	–
SPARIDAE											
Archosargus rhomboidalis	–	–	–	–	–	–	–	1	3	2	1

Taxa	A						B	C			
	Ahogado				Nearshore mangroves		Ahogado	Nearshore mangroves			
							Sand	Prop-root stations			
	Coral reef	Seagrass bed	Sand	Mangrove cay	Prop-root Station 4	Lagoon Station 5		1	2	3	4
SPHYRAENIDAE											
Sphyraena barracuda	–	–	–	–	–	–	–	–	6	1	1
SYNGNATHIDAE	1	–	–	–	–	–	–	1	2	–	
Unknown taxa	5(3)	2(2)	3(3)	–	–	–	16(3)	1(1)	3(2)	2(2)	–
Total number of fish	434	211	142	32	70	90	1081	108	157	124	137
Total number of larval fish	366	134	80	27	42	65	945	91	139	102	98
Total number of taxa	11	8	16	4	8	9	14	14	19	14	12
Total number of samples	4	4	4	4	12	12	9	9	9	9	9

shore mangrove habitats (prop-root and lagoon) showed higher levels of diversity than the mangrove cay station, but reduced catches.

Habitat effect was also observed during fall new moon collections at four nearshore mangroves sites. Significant patterns in larval and total fish abundance were detected among the four mangrove sites sampled ($\chi^2 = 12.887$, d.f. = 3, $P < 0.01$; $\chi^2 = 9.880$, d.f. = 3, $P < 0.05$). Of the three most abundant taxa collected with the nightlight lift-net, only *Harengula* spp. showed a significant ($P < 0.05$) habitat effect. No significant habitat effect was observed for the taxa *Albula vulpes* and Gerreidae. Overall, taxonomic diversity and catches among mangrove stations were relatively consistent; however, collections from Site 2 were slightly larger and more speciose than the other three sites. Also, taxonomic diversity during the fall new moon collections in nearshore mangrove was 1.5 to 2.0-fold greater than estimates determined in the same areas during lunar periodicity trials.

Table 2
Number of larval fish caught by habitat type during each lunar phase. Number in parentheses represent the proportion of the total number of larval fish caught for each respective habitat type

Habitat type	*N*	Moon phase				Total	χ^2	*P*
		Full moon	Last quarter	New moon	First quarter			
Ahogado								
Coral reef	4	4(1.1)	17(4.6)	336(91.8)†	9(2.5)	366	872.05	**
Mangrove cay	4	9(33.3)	4(14.8)	6(22.0)	8(29.6)	27	2.17	ns
Sand	4	6(7.5)	50(63.9)†	12(15.0)	12(15.0)	80	61.20	**
Seagrass	4	5(3.7)	27(20.1)	81(60.4)†	21(15.7)	134	97.52	**
Nearshore mangroves								
Prop-roots	12	11(26.2)	7(16.7)	14(33.3)	10(23.8)	42	2.38	ns
Lagoon	12	14(21.5)	9(13.9)	20(30.8)	22(33.8)	65	6.45	ns

Moon phase marked with a (†) are significantly greater ($P < 0.05$) than expected by chance.
** $P < 0.01$; ns, $P > 0.05$.

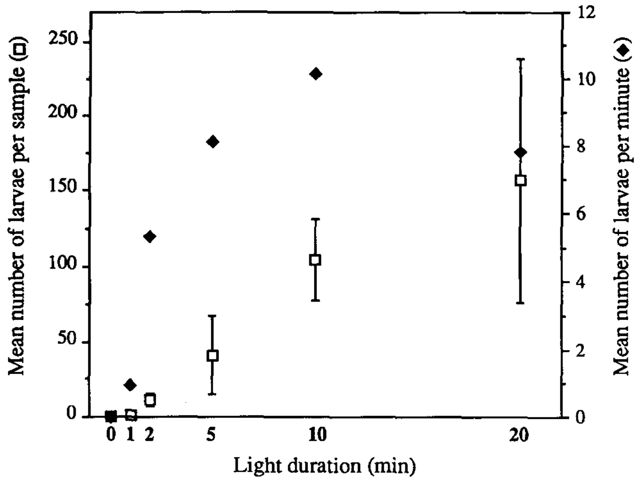

Fig. 3. Relationship between mean number of larvae collected with the nightlight lift-net and sample duration. Standard error bars (+ 1 SE) given for each light duration. Mean number of larvae collected per minute is also expressed for each sample duration.

3.4. Light duration

Marked increases in larval fish abundance occurred with increasing sample duration (linear regression $P < 0.01$). Linear and curvilinear (second-order polynomial) plots based on mean collection data are $N = 0.484 + 9.407 \times LD$ ($R^2 = 0.981$) and $N = -7.565 + 13.590 \times LD - 0.209 \times LD^2$ ($R^2 = 0.995$), respectively. Larva abundance is represented by N while LD indicates light duration. These data suggest a curvilinear relationship and appear to reach an asymptote at 20 min; however, there is little improvement in fit over a strict linear relationship. Although increasing sample duration increases catch, the number caught per unit time (i.e. light duration) does not follow this trend. Mean number caught per minute increases with increasing light duration up to 10 min (Fig. 3). Here, the maximum catch per unit effort is obtained (10.3 larvae per sampling minute). Further increases in light duration (i.e. 20 min) failed to increase number of larvae collected per minute (7.9 larvae per sampling minute). Curvilinear regression analysis, based on relative catch rates, showed the quadratic term to be significantly non-zero ($P < 0.01$; $R^2 = 0.702$) and the predictive plot was highest at 10 min. Coefficients of variation (CV) were also examined and the lowest estimate occurred for the 10 min light duration (CV = 50.0%). Estimates of variation for 5-min and 20-min samples were 103.7% and 85.5%, respectively. Consequently, catch per unit effort is maximized and variance is minimized during 10 min sampling periods.

3.5. Gear-type comparison

Relative abundances of larvae from night plankton tows (20:00 h) and the nightlight lift-net from the seagrass station were compared during preliminary trials in June 1988 ($P > 0.05$). Mean number of larval fishes collected by net tows and nightlighting were

11.67 (SE 1.20) and 20.33 (SE 3.29), respectively. Daytime plankton net tows (12:00 h) were also performed and mean number of larvae per 10 min tow was estimated as 0.33 (SE 0.33).

Trends in species composition and developmental stage were also present among methods. Ichthyofauna present in towed-net samples included only pre- and postflexion larvae (100%). Collections consisted of syngnathids (37%), clupeids (29%), atherinids (8%), and gobiids (8%). Conversely, nightlight collections were dominated by clupeids (79%) with albulid and engraulid larvae comprising most of the remaining taxa. In contrast to plankton tows, juveniles were relatively abundant in nightlight lift-net collections and accounted for 25% of total catch. The small number of fish collected in this phase of the study minimized quantitative evaluations and precluded statistical comparisons of catchability among methods.

4. Discussion

Nightlight lift-net collections differed from other nightlight methods used to sample tropical marine fishes in inshore habitats. Doherty's (1987) traps collected mostly pomacentrid larvae which were entirely absent in this study. By contrast, larval fish collections by Smith et al. (1987) and Victor (1986) were composed mostly of clupeid, gobiid, and blennioid larvae. In attempting to explain collection differences, Victor (1991) listed a number of factors both environmental and trap-related (e.g. geographic region, habitat, depth, time, lighting and nets), which could be responsible for observed differences. From additional trials at different locations and times of the year with the nightlight lift-net, we observed extreme spatial and temporal variability. For example, during May 1988, we deployed the nightlight lift-net in inshore waters off Mona Island, Puerto Rico. Mean number of larvae (about 200 per 10 min sample) greatly exceeded sample sizes observed in this study and taxonomic composition showed a three-fold increase over this study (Rooker and Dennis, unpublished data, 1988). Moreover, taxonomic composition and abundance varied greatly among habitats in close proximity (<0.5 km) at Mona Island with distinct assemblages occupying certain inshore areas. Overall, high numbers of larvae and/or juvenile blennioids, chaetodontids, clupeids, engraulids, labrids, pomacentrids, and scarids were collected. In sum, spatial and temporal patterns in larval composition and abundance create inherent biases. Therefore, it is very difficult to evaluate the selectivity of other light-aggregating designs used at different locations and times. However, we believe the nightlight lift-net trap provides two features which effectively reduce biases associated with other nightlighting techniques. First, the nightlight lift-net captures all larvae attracted to the light source without requiring them to enter windows (or slots) in a trap. Consequently, species-specific and size-specific biases (e.g. certain taxa avoid trap windows) are minimized providing a more robust measure of ichthyofaunal composition. Second, the device captures larvae in relatively short light periods (i.e. 10 min) allowing for replication of samples within a given night and reducing the opportunity for post-capture predation.

Temporal variability, primarily lunar periodicity, was also observed and appeared to significantly affect the numbers and types of larvae collected. Lunar periodicity significantly impacted nightlight collections of larval fishes in all habitats. The general trend observed in this study was high levels during the new moon and reduced numbers during the full moon period. This pattern is consistent with reports of lower larval fish settlement during the full moon when the moon is brighter and shining for longer periods (Ochi, 1985; Victor, 1986; Robertson, 1988). Size related differences in locomotory activity and light attraction response (i.e. effectiveness of light due to the background underwater light intensity), as well as physical factors (e.g. water clarity and current speed), may contribute to observed patterns. Moreover, lunar periodicity is possibly related to predation pressure. Predation on arriving settlers has been associated with light levels, with predatory risk often reduced during moonless nights (McFarland et al., 1985; Victor, 1986; Robertson et al., 1988). As a result, the activity patterns of larval fishes may vary depending upon light conditions. No significant lunar periodicities in catches were observed for juvenile and adult fish and this is consistent with the above interpretation since predatory risk generally declines as fish mature (Hixon and Beets, 1993).

Use of nightlighting as a quantitative method of sampling ichthyoplankton assemblages circumvents sampling problems encountered with conventional plankton gears in inshore habitats. However, the nightlight lift-net, as with any light sampling device, is inherently biased itself. Size and taxonomic selectivity are the two primary factors which differentiates the nightlight lift-net from conventional larval fish collection methods (Choat et al., 1993). Similar to Doherty's (1987) findings, the nightlight lift-net captured high numbers of larger, competent larvae (i.e. post-flexion stage) and juveniles. In fact, later stage post-flexion larvae accounted for the majority of larvae collected (91% of total larvae). Moreover, juvenile fishes were also collected in moderate numbers (15% of the total catch). Ichthyoplankton taken by net tows in this study were also primarily in post-flexion stages (80%); however, percentages were lower than light-traps and no juvenile fishes were collected. Gregory and Powles (1988) compared light-trap catches to towed net collections and also found a size selectivity bias. They concluded that the light-trap provided a more complete representation of size classes present and both sampling methods should be used to obtain proper size representation. A more comprehensive sampling protocol using the nightlight lift-net was initiated in southwestern Puerto Rico during 1988. Similar to previous findings, large numbers of post-flexion and juvenile stage ichthyofauna were collected; however, more parity existed among early and late stage larvae and thus a more complete range of sizes was collected. Preflexion and postflexion stage larvae accounted for 46% and 41% of total ichthyofauna, respectively.

Light-trap findings also showed that taxonomic composition is method dependent. Certain taxa such as haemulids, lutjanids, and serranids were rare or absent in our nightlight lift-net collections and noticeably lacking in other light-trap studies (Dennis et al., 1991; Riley and Holt, 1993; Choat et al., 1993). This finding is of particular interest since juveniles and adults of such taxa are dominant members of tropical inshore assemblages. The absence of many larval fish taxa in light-trap collections may be due to limited recruitment duration (1–3 days) for certain fish taxa. Using the nightlight lift-net, we observed recruitment of larval jewfish (*Epinephelus itajara*) into inshore habitats during September 1988 over only a 2 day period (Dennis et al., 1991). As a result, many larval taxa may be missed with monthly or quarterly sampling periods (Doherty, 1987). It is also possible that catch composition is selective and dependent on taxon photic behavior (i.e. not all taxa are photopositive and equally attracted to light). Since other studies using net-towed gears often reported fair numbers of these taxa (Gregory and Powles, 1988; Choat et al., 1993), it seems reasonable to conclude that variations in response to light plays a key role in trap selectivity. In fact, recent work has shown that nightlight collections are characterized by low taxonomic diversity compared with towed-net gears (Choat et al., 1993). Of six larval sampling techniques used (light-trap, seined-light, purse-seine, Neuston net, Bongo net and Tucker trawl) taxonomic diversity was lowest in light-trap collections indicating high taxonomic selectivity by this method. Consequently, when attempting to characterize ichthyoplankton assemblages the nightlight lift-net will be best used in conjunction with conventional towed net sampling, whenever possible. The combination of methods will provide a more complete picture of the larval assemblage. However, when certain taxa (i.e. photopositive species) are targeted or conditions (i.e. mangrove prop-roots) preclude the use of conventional towed-net gears, nightlighting alone may be a viable sampling method.

In addition to natural variability, collector-controlled light-trap options were also identified to influence catch. Light duration experiments indicate that optimal catch per unit effort (catch per minute) is attained after 10 min of illumination. Longer and shorter duration resulted in lower catch per unit time and increased coefficients of variation. Nightlighting attracts juvenile and adult stage taxa and short light duration may be preferred in order to reduce predation on larvae attracted to the light source. From a logistical standpoint, shorter light periods are also preferred because they reduce the problem of determining the volume sampled, inherent in long duration (i.e. overnight) deployments, and increase the number of samples permitted during each sampling night. Since our trap allowed all light-attracted ichthyofauna equal access (i.e. no size restrictions), shorter duration is probably preferable. However, a variety of other light-traps have small openings (i.e. windows) which restrict access of larger piscine predators that feed on the larvae. In such cases, a longer durations (e.g. 1–2 h) may be warranted, particularly if collections are made during periods when larval numbers are extremely low.

In summary, the nightlight lift-net method is simplistic in design, cost effective, and captures large numbers of larvae from inshore habitats in relatively short periods of time (i.e. 10 min). Therefore, the deployment of multiple units and replication of nightlighting samples, generally lacking from nightlight research due to high cost and logistical sampling constraints, becomes a viable option. Because nightlighting is gaining popularity as a sampling tool, there is a strong need for further studies on sampling performance of nightlighting gear to document the trap-specific nature of different light trap designs and operations. In particular, future research on sampling performance needs to address the effective draw of light traps (i.e. volume of water sampled), catch variation with different trap designs, and light source or intensity effects.

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