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## Comparison of Plankton Catch by Three Light-Trap Designs in the Northern Gulf of Mexico

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The ichthyoplankton catch and zooplankton biomass estimates of three light-trap designs—cylindrical, quatrefoil, and rectangular—were compared over three consecutive nights at an offshore petroleum platform in the northern Gulf of Mexico. The quatrefoil light trap had higher fish and zooplankton abundance estimates than the other two designs. Categorical analysis of the two abundant fish taxa, *Opisthonema oglinum* and *Anchoa* spp., indicated that catch by the quatrefoil and rectangular traps was similar, capturing more larvae than juveniles and more *O. oglinum* than *Anchoa* spp. relative to cylindrical trap catch. Across all fish species, the quatrefoil captured a greater percentage of larvae. Other ontogenetic and species-specific differences were noted among the light-trap designs. Samples from vertical plankton tows underestimated larger size classes compared to light-trap catch. Light-trap catch per unit effort (CPUE) declined through the night, especially for the quatrefoil, and increased with depth. In contrast, the percentage of larvae captured across all traps increased through the night and decreased with depth, indicating that CPUE was related mostly to juvenile catch. The percentage of larvae also decreased with increasing water current speed.

All planktonic sampling gears have biases in their collection of taxa and age classes. These sampling gears can be divided into two broad categories based upon their method of capture, active or passive (von Brandt, 1984), with some gear exhibiting characteristics of both (Rooker et al., 1996). Active gears, like towed nets and pumps, force water through mesh, functionally sieving organisms from the water. In contrast, passive gears rely upon other factors (e.g., natural water currents to bring plankton to stationary nets or the behavior of photopositive organisms to voluntarily enter light traps), which minimize avoidance and extrusion associated with active gears (Barkley, 1972; Hernroth, 1987). However, the effective volume of water sampled by light traps is often difficult to estimate and is dependent on a suite of environmental factors, including current speed, turbidity, and the ambient light field (Anderson et al., 2002; Lindquist and Shaw, 2005). Poorly understood species- and ontogenetic-specific behaviors also become increasingly important. Light-trap comparisons with active gears predominate comparative studies (Gregory and Powles, 1988), although comparisons with other passive gears are becoming more common (Choat et al., 1993; Hernandez and Lindquist, 1999; Hernandez and Shaw, 2003). These recent comparative studies have recommended that passive gears should be used in conjunction with active gears to better encompass the full spectrum of species composition, size ranges, and developmental stages.

Light-trap sampling gained popularity after Hungerford et al. (1955) mentioned their ability to sample early life stages of fishes. Light traps are typically deployed in structurally complex habitats that preclude sampling with conventional gears (Kawaguchi et al., 1986; Conrow et al., 1990; Hernandez and Shaw, 2003), although they can also effectively sample pelagic environments (Thorrold, 1992; Jones, 2006). In addition, data are accumulating on the species- and stage-specific selectivity of light traps (Gregory and Powles, 1988; Choat et al., 1993; Hickford and Schiel, 1999; Hernandez and Shaw, 2003). For example, the larger larval and juvenile stages of a number of taxonomic groupings such as pomacentrids, clupeiforms, scombrids, and carangids appear to always be well represented in light-trap samples (Doherty, 1987; Thorrold, 1993; Hernandez and Shaw, 2003). However, sampling efficiency among the various light-trap designs still remains relatively unknown (Hernandez and Lindquist, 1999; Jones, 2006). This is partially a result of there being several light-trap designs and light sources available. Furthermore, a given design is often modified so that no standardized, design-specific template exists, making within- and across-gear or across-habitat comparisons difficult. In order to better evaluate research findings from light-trap studies and among light traps, a comparison of differences in catch rate and in taxonomic and ontogenetic composition, as well as physical factors affecting these parameters, is necessary (Lindquist and Shaw, 2005). The objective of this study is to

explore such catch characteristics among three popular light-trap designs.

#### METHODS

*Collection.*—Sampling was conducted at Mobil's West Cameron 71D oil platform located off western Louisiana in 11 m of water (29°37'18"N, 93°10'32"W). Because fish recruitment may be coupled with lunar cycles (Kingsford and Finn, 1997), samples were collected over three consecutive nights, 21 July–24 July 1994, during a full moon phase. Logistical and personnel constraints prevented us from additionally sampling during the new moon period. All sampling commenced and terminated at least 1 hr after sunset and before sunrise, respectively. Three light trap designs—a cylindrical trap (an acrylic model with the removable bottom catch cup replaced by a small conical plankton net with 235- $\mu\text{m}$  mesh and cod end; Riley and Holt, 1993), a cloverleaf-shaped quatrefoil (Hernandez and Shaw, 2003), and a 3-chambered rectangular trap (modified from Doherty, 1987 and described by Röpke et al., 1999)—were deployed consecutively along a guideline attached to the bottom within the platform structure. Sampling depths included 1-m (surface, all three nights) and 8.5-m depths (Night 3 only). A set of samples was defined as one 15-min sample by each of the three light traps. Trap order was randomized within each set. In addition, six vertical (8.5 m to surface; volume filtered = 2.4  $\text{m}^3$ ) plankton tow samples [202- $\mu\text{m}$  mesh, 60-cm diameter net, density or catch-per-unit-effort (CPUE) = fish  $\cdot \text{m}^{-3}$  and zooplankton dry weight biomass = mg  $\cdot \text{m}^{-3}$ ] were collected during Night 2. All fish in each sample were identified and measured. Each fish was assigned a life-history stage, larva or juvenile, as defined by Ahlstrom et al. (1976), based on standard length. The plankton samples, excluding fish, were then dried to constant weight ( $\pm 0.01$  g) for an estimate of zooplankton biomass (Lovegrove, 1966).

Water temperature (C) and salinity (ppt) were measured at sample depth with a Beckman Industrial electrodeless induction salinometer (Model RS5-3). Water current ( $\text{cm} \cdot \text{s}^{-1}$ ) was measured at sample depth with a Montedoro-Whitney PVM-2 portable flow velocity meter. Suspended sediment load (dry weight in mg  $\cdot \text{liter}^{-1}$ ), an approximate for turbidity, and percentage of organics within the suspended load were determined from filtered water samples taken at the surface (APHA, 1976). Photosynthetically active radiation (PAR) at about 1-m depth and scalar (ambient) irradiance or refer-

ence PAR ( $E_0$  PAR) at the platform sampling deck was measured (microeinsteins  $\cdot \text{m}^{-2} \cdot \text{s}^{-1}$ , where 1  $\mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1} \approx 51.2$  lux or lumens  $\cdot \text{m}^{-2}$ ; Valiela, 1984) using a Biospherical Instruments PNF-300 profiling natural fluorometer.

*Trap designs.*—The three light trap designs had unique physical characteristics (Table 1). All designs were similar in total height and in entrance gap width. All were constructed from transparent acrylic plastic and had four entrances, which were beveled toward the trap interior. All entrance slots were vertical in the cylindrical and quatrefoil traps, whereas the rectangular trap had two vertical and two horizontal slots. The rectangular trap had the greatest internal surface area and volume, and the quatrefoil had the greatest internal entrance area (i.e., the narrowest component of the entrance). The cylindrical trap was lowest in these three measurements. Because the entire lateral surface of the quatrefoil is beveled into a four-leaf-clover design, the quatrefoil external entrance area (i.e., the widest component of the entrance) was nearly an order of magnitude larger than the other designs. The cylindrical and quatrefoil traps were single-chamber designs, whereas the rectangular trap consisted of three chambers, each separated by bevels that led progressively away from the trap entrance. The cylindrical and quatrefoil traps were both lit with the same bright halogen bulb. The rectangular trap was lit with three fluorescent bulbs, one in each chamber; the bulbs were turned on and off sequentially so that organisms were drawn toward and accumulated within the innermost chamber. The rectangular trap was specifically designed for remote sampling over a number of days, which necessitated the use of an energy-efficient, battery-powered light source; hence, fluorescent lights were used.

*Statistical analyses.*—CPUE (number of fish  $\cdot \text{min}^{-1}$ ), zooplankton dry weight biomass (mg  $\cdot \text{min}^{-1}$ ), and percentage of larvae (number of larvae/total number of larval and juvenile fish in sample) for surface light-trap catches were analyzed with stepwise multiple regression procedures (SAS, 1989). Light-trap design was included as a qualitative variable using the quatrefoil as the reference design. Turbidity and current speed were entered as quantitative variables. Models also included night and hour, as well as interaction and orthogonal polynomial terms that could be important in explaining the response variance. Similar models were constructed with data collected only during Night 3 to include the effect of depth (1 m vs 8.5 m) to

TABLE 1. Measurements and characteristics of the three light-trap designs used during the study. Trap height includes the conical plankton net with cod end at the bottom of the cylindrical and quatrefoil traps used to collect the draining sample when the traps are removed from the water. The cylindrical and quatrefoil traps used the same light source.

Trap design	Cylindrical	Quatrefoil	Rectangular
Total trap height (cm)	101.5	144.8	129.5
Average entrance gap (cm)	0.8	1.0	1.3
Entrance surface area (cm <sup>2</sup> )			
Internal	57.6	177.8	100.0
External	864.0	5,597.1	640.0
Internal surface area (cm <sup>2</sup> × 10 <sup>3</sup> )	8.6	13.0	17.1
Internal volume (cm <sup>3</sup> × 10 <sup>3</sup> )	35.0	69.0	107.7
Net mesh size (µm)	235	202	500
Light source	One 12-volt halogen fishing light (Brinkmann Starfire II); 250,000 candle power output ≈ 2,677,824 lumens; 2,000–3,000 K color temperature		Three 6-watt, 6-volt, fluorescent tubes (CoolWhite GE F6T5); 295 initial and 235 mean lumens output; 4,100 K color temperature
Citation	Riley and Holt (1993)	Hernandez and Shaw (2003)	Röpke et al. (1999)

investigate possible depth stratification or diel vertical migration (Richards et al., 1996); turbidity was omitted from the Night 3 analyses, because it was not measured at depth. Candidate models were evaluated with residual, influential, partial, and collinearity diagnostics (Belsley et al., 1980; Neter et al., 1996). The CPUE and zooplankton biomass estimates were natural log (log<sub>e</sub>) transformed before the analyses. Percentage of larvae was transformed by the following equation:

$$\frac{1}{2} \left( \arcsin \sqrt{\frac{x}{n+1}} + \arcsin \sqrt{\frac{x+1}{n+1}} \right),$$

where  $x$  = the number of larvae and  $n$  = the total number of fish in the sample. This transformation is desirable if values contain many small and large proportions (Zar, 1984). To test for equal intercepts between the light-trap designs, a studentized t-test was calculated as  $t^* = (b_i - b_j) / s\{b_i - b_j\}$ , where  $s^2\{b_i - b_j\} = s^2\{b_i\} + s^2\{b_j\} - 2s\{b_i, b_j\}$ ;  $b_i$  is the estimated intercept of trap  $i$ ,  $s^2\{b_i\}$  is the variance of  $b_i$ , and  $s\{b_i, b_j\}$  is the covariance between  $b_i$  and  $b_j$  (Neter et al., 1996).

The Bray-Curtis similarity coefficient (Boesch, 1977) was calculated for each pair of light traps to evaluate the overlap of fish taxa caught by the traps. The coefficient of variation (CV = 100 × standard deviation/mean) for CPUE and biomass was also calculated for each light trap to compare variability across trap designs. Correlation coefficients ( $r$ ; Zar, 1984) were calculated between CPUE and biomass and between sus-

pended solids and percentage of organics in the solids to determine the strength and direction of their relationships.

Life history stage of dominant fish taxa caught by the different light traps was compared with a loglinear model (SAS, 1996). Catch by vertical plankton tows was not included in the analysis, because the net obtained only larval stages. This categorical analysis is specifically designed for count data and tends to be conservative. A parametric test was undesirable because of the low counts in some of our cells. This categorical (stage) model was preferred over a traditional length-frequency analysis because we were also interested in differences among other factor levels, i.e., trap design and species. The contingency table consisted of marginal counts summed over all sets and included light-trap design, life history stage, and species as main effects. The appropriateness of the inclusion of interaction terms in the model was evaluated by comparison of the deviances generated by various models (Agresti, 1996).

Only *Opisthonema oglinum* (Atlantic thread herring) and *Anchoa* spp. (anchovies) had sufficient numbers to compare life history stages among the light-trap designs. Although two species of *Anchoa* were identified, these were combined into a single *Anchoa* grouping for this analysis, resulting in a 2 × 2 × 3 contingency table. In the initial analysis, the cylindrical trap produced large adjusted Pearson residuals (3.40). One set taken at 8.5-m depth on Night 3 was excluded because of an unusually high catch of *Anchoa* juveniles by the cylindrical trap.

TABLE 2. Mean values of physical parameters measured at 1-m depth over the three nights of the study, with the sample size and the standard deviation in parentheses. Ambient irradiance and photosynthetically active radiation (PAR) were measured on Night 1 only; ambient irradiance was measured at the platform's sampling deck.

	Night 1	Night 2	Night 3
Temperature (C)	30.02 (18; 0.16)	29.76 (24; 0.12)	29.91 (12; 0.09)
Salinity (ppt)	21.23 (18; 0.26)	25.13 (24; 0.35)	28.02 (12; 0.15)
Current speed (cm · s <sup>-1</sup> )	20 (53; 5)	12 (72; 4)	4 (36; 2)
Suspended load (mg · liter <sup>-1</sup> )	12.37 (4; 1.24)	9.95 (5; 3.45)	8.47 (4; 4.26)
Percent organics	29.59 (4; 0.53)	28.70 (5; 5.51)	40.53 (4; 7.69)
Ambient irradiance (μE · m <sup>-2</sup> · s <sup>-1</sup> )	0.106 (6; 0.039)		
PAR (μE · m <sup>-2</sup> · s <sup>-1</sup> )	0.056 (12; 0.043)		

Nearly half (22/53) of all *Anchoa* caught by the cylindrical trap were obtained in this one sample; all were *Anchoa nasuta* and all but one were juveniles. Elimination of this set resulted in a homogeneous association model that explained nearly all of the variance (deviance = 0.63,  $P > 0.25$ ). Thus, results were interpreted through estimated conditional odds ratios (Agresti, 1996).

## RESULTS

Over the course of the 3-d study, surface salinity increased at the sample site, while current speed and suspended load decreased (Table 2). At the platform's sampling deck, the mean ambient irradiance was  $0.106 \mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1} \pm 0.039 \text{ SD}$  ( $5.43 \text{ lumens} \cdot \text{m}^{-2} \pm 2.01$ ), whereas at about 1-m depth, the mean PAR was  $0.056 \mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1} \pm 0.043$  ( $2.87 \text{ lumens} \cdot \text{m}^{-2} \pm 2.18$ ).

Twenty samples (300 min total sampling time) were collected by each light-trap design. A total of 477 larval and juvenile fish representing 13 families were identified (Table 3). The rectangular trap captured a total of three families. Nine families were captured by the cylindrical trap, with three families (Blennidae, Stromateidae, and Bothidae) collected exclusively by that design. Ten families were captured by the quatrefoil, with four families (Exocoetidae, Gobiidae, Microdesmidae, and Cynoglossidae) collected exclusively by that design. Individuals from families captured by only one light-trap design, however, were rare. *Opisthonema oglinum* was the most abundant species (39.2% of the total catch), followed by *Anchoa* spp. (26.0%). *Anchoa* included at least two species; of those which were identified to species, 31.4% were *Anchoa hepsetus* (striped anchovy) and 68.6% were *A. nasuta* (longnose anchovy). *Harengula jaguana* (scaled sardine) and *Chloroscombrus chrysurus* (Atlantic bumper) were also common. These four coastal pelagic taxa accounted for over 86% of the total catch.

The stepwise multiple regression on surface CPUE (Table 4A) and zooplankton biomass estimates (Table 4B) resulted in significant models. Quatrefoil CPUE and biomass estimates were significantly greater than the other designs, which were not significantly different from each other ( $t^* = 0.9929$ ,  $P = 0.1634$  and  $t^* = 0.5660$ ,  $P = 0.2876$ ). However, CPUE decreased for the quatrefoil throughout the night, while CPUE for the other designs remained relatively constant. A curvilinear decrease in CPUE was also noted over the three-night period. Although biomass estimates were moderately and positively correlated with CPUE ( $r = 0.81$ ), the variation in CPUE explained by biomass estimates was largely a linear function of other predictor variables in the model. The biomass model indicated that zooplankton biomass estimates decreased over the three-night period, perhaps due to changes in the physical environment (Table 2). Although the positive relationship between biomass estimates and turbidity could be a sampling artifact, because our turbidity estimation technique (dry weight) also measured biomass, a low and negative correlation between suspended solids and percent organics in the solids ( $r = -0.39$ ) suggested otherwise.

The quatrefoil captured a significantly greater percentage of larvae than both the cylindrical and rectangular traps (Table 4C), whereas the percentage caught by the cylindrical and rectangular traps was not significantly different ( $t^* = 0.6296$ ,  $P = 0.2664$ ). The percentage of total larvae collected increased throughout the night. However, the rate of increase was greatest on the second night and least on the third night as indicated by the significant quadratic night component. In addition, the percentage of larvae captured was inversely related to current speed.

Four samples were collected by each light-trap design at both surface and 8.5-m depths during the third night. Only light-trap design and depth entered the CPUE stepwise multiple regression

TABLE 3. Fish taxa caught by three light-trap designs and vertical plankton net tows. Values indicate total number of fish caught and, within the parentheses, the number of positive catch samples (out of 20 light-trap samples and six net samples) and fish size range (mm), respectively. If only one fish was obtained, only the length of that fish is given. Dagger (†) indicates that fish were not measured due to damage. For the two taxa that entered into our categorical statistical model, i.e., *Opisthonema oglinum* and *Anchoa* spp., the numbers within the brackets indicate number caught by stage: L = larvae and J = juvenile. The Bray-Curtis similarity coefficients for taxa counts are given for each trap, where C = the coefficient between the cylindrical trap, Q = quatrefoil, and R = rectangular. CV indicates coefficient of variation.

Taxon	Cylindrical	Quatrefoil	Rectangular	Net
Teleostei	—	—	2 (2; †)	3 (1; †)
Clupeiformes	—	—	1 (†)	—
<i>Anchoa</i> spp.	2 (2; 4.0–7.5)	35 (9; 1.7–10.3)	1 (3.3)	22 (5; 1.8–9.0)
<i>Anchoa hepsetus</i>	9 (6; 6.0–28.5)	11 (4; 2.4–28)	7 (4; 10.5–21.0)	1 (9.5)
<i>Anchoa nasuta</i>	42 (5; 18.3–30.5)	16 (8; 21.0–38.7)	1 (27.5)	—
Total <i>Anchoa</i>	[9 L : 22 J]	[47 L : 14 J]	[6 L : 1 J]	[23 L : 0 J]
<i>Anchoviella perfasciata</i>	1 (28.5)	3 (3; 24.6–33.0)	1 (25.4)	—
<i>Harengula jaguana</i>	11 (8; 16.0–27.0)	36 (13; 13.9–32.5)	9 (5; 19.5–35.0)	—
<i>Opisthonema oglinum</i>	38 (12; 2.5–26.0)	123 (19; 1.8–29.0)	26 (12; 2.2–24.0)	11 (3; 2.5–13.0)
	[4 L : 21 J]	[62 L : 50 J]	[9 L : 9 J]	[11 L : 0 J]
<i>Synodus foetens</i>	2 (2; 31.0–33.0)	4 (2; 30.3–35.5)	—	—
<i>Hyporhamphus unifasciatus</i>	—	3 (3; 27.0–34.0)	—	—
Perciformes (preflexion)	1 (1.7)	19 (5; 0.9–1.7)	1 (1.5)	6 (1; 1.3–1.8)
<i>Chloroscombrus chrysurus</i>	2 (1; 1.8–2.0)	45 (12; 1.1–24.0)	—	7 (4; 2.3–7.5)
Sciaenidae	3 (1; 1.8–2.0)	2 (1; 1.5–1.6)	—	—
<i>Cynoscion arenarius</i>	1 (2.2)	4 (2; 2.5–3.0)	—	1 (3.5)
<i>Stellifer lanceolatus</i>	1 (3.5)	3 (3; 3.0–3.5)	1 (2.3)	1 (2.6)
Blennidae	1 (2.3)	—	—	—
Gobiidae	—	1 (2.5)	—	—
<i>Microdesmus longipinnis</i>	—	1 (18.0)	—	—
<i>Scomberomorus maculatus</i>	1 (9.5)	2 (2; 2.7–5.6)	—	—
<i>Peprilus alepidotus</i>	1 (3.0)	—	—	—
Bothidae	1 (2.3)	—	—	—
<i>Symphurus</i> spp.	—	2 (2; 2.7–3.6)	—	—
Total taxa (Families)	16 (9)	17 (10)	10 (3)	8 (4)
Total fish	117	310	50	52
Mean fish/sample (range)	6 (0–37)	16 (2–37)	3 (0–12)	9 (3–23)
Mean CPUE (SD)	0.39 (0.58)	1.03 (0.63)	0.17 (0.20)	3.61 (3.29)
Mean biomass (SD)	2.8 (2.6)	25.2 (12.7)	2.2 (2.3)	120.7 (18.8)
Bray-Curtis coefficient	0.60 Q/0.56 R	0.60 C/0.63 R	0.56 C/0.63 Q	
CV CPUE/biomass	148.8/92.6	60.6/50.5	118.6/104.6	91.3/15.6

model (Table 5). Overall, CPUE was significantly greater at depth. The quatrefoil CPUE was significantly greater than the other designs, which were not significantly different from each other ( $t^* = 1.4120$ ,  $P = 0.0871$ ). Only light-trap design entered the zooplankton biomass model, resulting in an analysis of variance model ( $r^2 = 0.53$ ). Biomass estimates for the quatrefoil were significantly greater ( $P = 0.0004$ ) than for the other two designs, which were not significantly different ( $t^* = 0.0193$ ,  $P = 0.4924$ ). Percentage of larvae was marginally affected by depth ( $r^2 = 0.14$ ,  $P = 0.0728$ ), with higher proportions of juveniles, relative to larvae, caught at 8.5 m. Thus, percentage of larvae tended to decrease

with depth and to increase through the night (Table 4C), while CPUE exhibited the opposite trends (Tables 4A and 5). This indicates that CPUE was related to juvenile catch.

The categorical analysis on *O. oglinum* and *Anchoa* spp. revealed species- and stage-specific differences among light-trap designs. With the effect of trap design held constant, the estimated conditional odds ratio of capturing an *O. oglinum* juvenile were 2.8 times that of capturing an *Anchoa* juvenile (Table 6). Larval and juvenile *O. oglinum* were caught in approximately equal numbers (75 larvae : 80 juveniles); however, *Anchoa* larvae (62) were caught in greater numbers than juveniles (37). With species held

TABLE 4. Summary of the stepwise multiple regression analysis on natural log-transformed surface A) catch per unit effort ( $r^2 = 0.85$ ), B) zooplankton biomass estimates ( $r^2 = 0.82$ ), and C) arcsin-transformed percentage of larvae ( $r^2 = 0.66$ ). The analysis of variance portion gives the source of variation (Source), the degrees of freedom (DF), sum of squares (SS) for that source, and the significance of the model. Parameter estimates, standard error (SE), and the probability that the estimate equals zero are also listed. The quatrefoil was the reference design for the qualitative light-trap variables.

A.	Source	DF	SS	P
	Model	7	3.3290	0.0001
	Error	40	0.6102	—
	Variable	Estimate	SE	P (b = 0)
	Intercept	0.6034	0.0311	0.0001
	Night	-0.0839	0.0239	0.0011
	Night (quadratic)	0.0371	0.0125	0.0050
	Hour	-0.0382	0.0070	0.0001
	Cylindrical	-0.4486	0.0438	0.0001
	Rectangular	-0.4922	0.0437	0.0001
	Cylindrical * hour	0.0366	0.0102	0.0009
	Rectangular * hour	0.0272	0.0101	0.0100
B.	Source	DF	SS	P
	Model	4	52.9109	0.0001
	Error	34	11.8189	—
	Variable	Estimate	SE	P (b = 0)
	Intercept	2.1539	0.3740	0.0001
	Cylindrical	-2.1956	0.2313	0.0001
	Rectangular	-2.3265	0.2313	0.0001
	Night	-0.2795	0.1363	0.0482
	Turbidity	0.0988	0.0329	0.0049
C.	Source	DF	SS	P
	Model	6	8,354.0088	0.0001
	Error	37	4,386.7333	—
	Variable	Estimate	SE	P (b = 0)
	Intercept	66.7287	4.3645	0.0001
	Hour	1.2733	0.4057	0.0033
	Night (quadratic)	5.5189	1.2377	0.0001
	Current	-93.1079	24.9794	0.0006
	Cylindrical	-11.9296	3.9408	0.0045
	Rectangular	-9.3071	4.1674	0.0317
	Hour * night	-1.1122	0.5173	0.0382

constant, the odds ratios of capturing a juvenile with the cylindrical trap were over seven times that of capturing a juvenile with either the quatrefoil or rectangular traps. The cylindrical trap was more adept at capturing juveniles than larvae (13 larvae : 43 juveniles). The quatrefoil and rectangular traps obtained higher percentages of larvae (63% and 60%, respectively), and the odds of capturing a juvenile with the quatrefoil and rectangular traps was not significantly different from one. Holding life-stage constant, the odds ratios of capturing *Anchoa* with the cylindrical trap were 5.0 and 3.6 times the odds of capturing *Anchoa* with the quatrefoil and rectangular traps, respectively. The odds ratio comparing the catch of the quatrefoil and rectangular traps was not significantly different from one. Greater numbers of *O. oglinum*,

relative to *Anchoa*, were captured by the quatrefoil (112 *O. oglinum* : 61 *Anchoa*) and rectangular (18 : 7) traps. Note that the set excluded from this analysis supports the result that the cylindrical trap was more adept at capturing juvenile *Anchoa*.

Although *H. jaguana* and *C. chrysurus* were abundant overall, their numbers were too low across factor levels for statistical analysis. Numbers of *H. jaguana* were equally distributed across the three nights. The rectangular trap captured only juvenile *H. jaguana*, whereas the cylindrical and quatrefoil traps caught approximately 75% juveniles (9 and 26 juveniles, respectively). *H. jaguana* was not present in the vertical plankton net samples. Overall, larval stages dominated the *C. chrysurus* catch. The quatrefoil caught the only four juveniles, whereas the rectangular trap did

TABLE 5. Summary of the depth (1 m vs 8.5 m) stepwise multiple regression analysis on natural log-transformed catch per unit effort, third night only ( $r^2 = 0.68$ ). See Table 4 for explanation.

Source	DF	SS	P
Model	3	2.1580	0.0001
Error	19	0.9940	—
Variable	Estimate	SE	P (b = 0)
Intercept	0.5378	0.0940	0.0001
Depth	0.3525	0.0957	0.0016
Cylindrical	-0.4118	0.1186	0.0025
Rectangular	-0.5792	0.1144	0.0001

not catch *C. chrysurus*. Based on all fish taxa (Table 3), the catch between the quatrefoil and rectangular traps was the most similar (63%), and catch between the cylindrical and rectangular traps was the least similar (56%).

DISCUSSION

Light-trap design produced pronounced differences in both CPUE and zooplankton biomass estimates. Similar results have been previously reported. Hernandez and Lindquist (1999) and Clavijo et al. (1996) reported that their three-chambered rectangular light trap was more efficient at capturing zooplankton and ichthyoplankton than a two-chambered design. Meekan et al. (2001) tested two different sizes of rectangular traps and found that the smaller design captured more reef fish than the larger design. Mean CPUE by each light-trap design in this study falls within ranges reported in the literature. In contrast to catches in tropical habitats (e.g., Choat et al., 1993), the rectangular-trap catch during the present study is positioned in the lower portion of this range, possibly emphasizing the importance of temporal and spatial differences among studies and of variations in light-trap design.

Other subtle but important differences were found among the light-trap designs at ontogenetic and taxonomic levels. Although the cylindrical

and quatrefoil traps caught a similar number of taxa, the cylindrical trap tended to sample mostly juveniles, whereas the quatrefoil was more effective at sampling larvae. Considering the two most abundant taxa, the cylindrical trap captured a greater percentage of *Anchoa* spp., whereas the quatrefoil and rectangular traps collected a greater percentage of *O. oglinum* specimens. The rectangular trap captured no *C. chrysurus*, and the quatrefoil caught the only juveniles. The rectangular trap collected only juvenile *H. jaguana*, whereas the other two designs also obtained larval stages. Moreover, the similarity over all taxa was about 60% between traps.

Several factors may have contributed to the differences in catch among the light-trap designs. The rounded shape of the cylindrical and quatrefoil traps may facilitate entry, because movement along the lateral external surface of the trap eventually leads to an entrance. The entire lateral surface of the quatrefoil collection chamber is curved inward to the entrances, providing more opportunities for an organism to orient itself with the entrance. If escapement is a function of random movements, then a trap with a large internal surface area or volume may retard escapement (Munro, 1974). However, the rectangular trap, which has both the largest total internal surface area and volume, had the lowest catch rate. Any retention advantage, however,

TABLE 6. Results from the loglinear regression analysis on life history stage (J = juvenile, L = larva), species (A = *Anchoa* spp., O = *Opisthonema oglinum*), and trap design (C = cylindrical, R = rectangular, Q = quatrefoil). For each parameter, the estimated conditional odds ratios ( $\hat{\theta}$ ), the Wald  $\chi^2$  statistic, and the probability that  $\hat{\theta} = 1$  is given. To ease interpretation, odds ratios are calculated so that  $\hat{\theta} > 1$ .

Parameter estimated	$\hat{\theta}$	$\chi^2$	p( $\hat{\theta}=1$ )
Stage (J/L) * species (O/A)	2.76	11.07	0.0009
Stage (J/L) * trap design (C/Q)	7.66	28.41	< 0.0001
Stage (J/L) * trap design (R/Q)	1.06	0.02	0.8907
Stage (J/L) * trap design (C/R)	7.20	13.05	0.0003
Species (A/O) * trap design (C/Q)	3.61	12.96	0.0003
Species (A/O) * trap design (Q/R)	1.38	0.45	0.5039
Species (A/O) * trap design (C/R)	4.98	8.38	0.0038



may have been minimized by the short duration of the deployments (Fogarty and Addison, 1997).

Organisms typically show a higher affinity toward greater light intensities and may respond differently to various wavelengths of light emitted by different types of light bulbs (Kawamoto, 1959; Blaxter, 1968; Gehrke, 1994). In addition, the oil platform studied was lit for on-site and navigational safety reasons and, therefore, produced a competitive light field, which was compounded by a full moon phase. However, our on-site measurements of the ambient light field and PAR at 1-m depth were low, i.e., 5.43 and 2.87 lumens  $\cdot$  m<sup>-2</sup>, respectively, compared to the lowest trap light source, i.e., 295 initial lumens with a mean of 235 lumens. In addition, our ambient irradiance and PAR measurements at a single platform were very similar to those measured by Keenan et al. (2007; mean ambient irradiance = 5.73 lumens  $\cdot$  m<sup>-2</sup>  $\pm$  22.6 and 1-m depth PAR = 1.67 lumens  $\cdot$  m<sup>-2</sup>  $\pm$  1.28) for three of their platforms—Pr2, Gdk, and Yke—at the edge of the South Timbalier 151 complex, which consisted of a cluster of six fixed-leg platforms. Still, the rectangular trap's much dimmer fluorescent lights (235 vs 2,677,824 lumens) may have been at a distinct disadvantage, although no statistically significant differences were found in total CPUE or biomass between the cylindrical and rectangular traps. Water turbidity further reduced the effective sampling radius of the light field for all designs. Lindquist and Shaw (2005) found that CPUE of larval and juvenile fishes decreased with increasing water turbidity. Fisher and Bellwood (2002) used a light-trap design with baffles and showed that light intensity decreased rapidly with distance due to attenuation and increasing area of illumination. The variety of light-trap shapes, entrance configurations, and materials cast different reflected and scattered light fields. These differing light projections may influence the behavioral responses of organisms at trophic, ontogenetic, and species-specific levels (Hargreaves et al., 1993; Higgs and Fuiman, 1996; Hernandez and Lindquist, 1999; Lindquist et al., 2001). Consequently, each light trap may have also produced a different density gradient of photopositive zooplankton in response to the different light fields, which can influence the feeding reflex in fish (Keenan et al., 2003) and may also explain why some fish species that are not particularly photopositive are captured by light traps. If fish are attracted to zooplankton prey items that are, in turn, attracted to the light given off by the traps, then traps with higher zooplankton biomass estimates could have a higher CPUE. This is supported by the finding

that both zooplankton biomass and CPUE decreased over our 3-d study. Therefore, differences in light intensity, light quality, light projection, and food density are likely to interact and to influence catch.

One issue concerning light-trap comparisons with conventional towed gears that is not yet fully resolved is the effective size range of fish caught by light traps. Gregory and Powles (1988) found that light traps were more effective at sampling smaller larvae and larger juvenile fish than was a Miller high-speed sampler. Hernandez and Shaw (2003) found that light traps were very good at collecting larger size classes, but also substantially overlapped with smaller size distributions from passive, nocturnal plankton net collections. Other studies have noted that light traps select for larger individuals only. In the present study, the vertical plankton tows, relative to the light-trap catches, did not collect larger size classes, indicating either nocturnal net avoidance or that these size classes were more rare and, therefore, not adequately sampled by the small volume of water filtered (2.4 m<sup>3</sup>). In addition, the effectiveness of capturing larval fish varied among the light-trap designs tested. Gregory and Powles attributed their finding to extrusion of smaller larvae by the towed gear. Choat et al. (1993) and Brogan (1994) explained differences between studies as taxon- and habitat-specific variation. However, differences in the current regime among the study areas cannot be ignored, especially when dealing with passive planktonic gears and their sampling volumes. Gregory and Powles (1985) stated the flow in their study area was negligible, whereas Choat et al. (1993) cited a flow rate of 15 cm  $\cdot$  s<sup>-1</sup>, which is comparable to that observed during the present study (mean = 12 cm  $\cdot$  s<sup>-1</sup>) and to those generally observed in our area, i.e., 5–15 cm  $\cdot$  s<sup>-1</sup> (Shaw et al., 1985). During this study, some smaller, less-competent larvae may have been advected past the trap before they could enter. This hypothesis was proposed by Thorrold (1992) to explain the higher catch of drifting light traps relative to tethered traps. Further credence is given by the significant and negative relationship between current speed and percentage of larvae captured in the present study. However, Lindquist and Shaw (2005) found that not only did CPUE decrease with increasing current speed, but so did fish size, to the point where at the highest speeds, only preflexion larvae were collected, presumably by passive filtration. Even microscale currents immediately around or within each trap design may differ, acting to enhance or retard entry into or retention within the trap. Such small-scale turbulence immediately around light

traps may lead to decreased CPUE at current speeds greater than  $30 \text{ cm} \cdot \text{s}^{-1}$  (Lindquist and Shaw, 2005). For example, in this study, the cylindrical trap occasionally began to spin in the current while fishing, which would undoubtedly affect ingress.

One statistical measure of precision or reproducibility that allows for comparison of catch among the light-trap designs is the coefficient of variation (CV; Table 3), where lower values indicate higher precision and statistical power. The quatrefoil's CV for both zooplankton biomass and CPUE was nearly half that of the cylindrical and rectangular designs. The rectangular trap's CV for CPUE was slightly lower than the cylindrical trap's CV, but it was slightly higher for biomass. Given the quatrefoil's overall performance, it was selected for subsequent use in a number of platform-based studies (Hernandez and Shaw, 2003; Lindquist and Shaw, 2005; and studies cited within). The findings from this trap-comparison study are based on sampling at a structurally complex environment during a short-term period and may not apply to other environments. Confirmation at other locations over larger time scales may be necessary to enable researchers to objectively choose the most appropriate design for their particular environment, current regime, and planktonic community.

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