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The relationship between the vertical distribution of spiny lobster phyllosoma larvae (Crustacea: Palinuridae) and isolume depths generated by a computer model

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Resumen: Durante un muestreo de zooplancton (Programa SEFCAR: *S*outh*E*astern *F*lorida and *CA*ribbean *R*ecruitment) en los cayos de la Florida, se encontró que las larvas filosomas de *Panulirus* spp. (80% estadíos I-II) migran verticalmente de 20-40 m en el día a 0-20 m durante la noche. Hubo cierta coincidencia entre profundidades de "isolúmenes" generados por un modelo de computadora, y la distribucíon vertical, aunque ésta no es estadísticamente significativa, tal vez debido a la heterogeneidad espacial y física. Los mecanismos que controlan la migración vertical diaria posiblemente también son complejos.

Key words: vertical migration, light, model, recruitment, phyllosoma, Florida.

Diel vertical migration (DVM) of spiny lobster (*Panulirus* spp.) phyllosoma larvae may be a key component in the biological-physical coupling which affects their transport and survival in the Florida Keys. Light is often invoked as the most important factor to influence DVM (Angel 1985). In this study, we describe the diel changes in the vertical distribution of *Panulirus* spp. phyllosomata. We then use a computer model to hindcast irradiance in the water column associated with the vertical distribution patterns, and explore the possible correlation between them. The ability to predict the vertical distribution of phyllosomata with a light model will be useful in quantitative sampling and in the modeling of larval transport and recruitment mechanisms.

Phyllosomata were collected in the Florida Keys during a *S*outh*E*astern *F*lorida and *CA*ribbean *R*ecruitmext (SEFCAR) zooplankton survey, May 23-28, 1990. Sampling plan and methods were described in Yeung and McGowan (1991). During each 1-m^2 MOCNESS (*M*ultiple *O*pening/*C*losing *N*et and *E*nvironmental *S*ensing *S*ystem, Wiebe et al. 1976) tow, five 20 m strata were sampled from 0-100 m, two 30 m strata from 100-160 m, and one 40 m stratum from 160-200 m. Two series of 24-hr sampling were conducted at fixed stations: i) 241-244 ii) H1-H2 (Fig. 1, Table 1).

Mean abundances (standardized to $n \cdot 10\ m^{-2}$) were not different between day and night stations (t-test P=0.937), thus, no adjustment was made for avoidance. The center of concentration (C) was used to describe vertical distribution at each station, and was calculated as:

$$C = \sum_{i}^{n} (P_i \times Z_i)$$

C = center of concentration (m)
n = number of depth strata sampled in one tow
Z_i = mean depth of i^{th} sampling stratum (m)
P_i = % concentration ($n/1000m^3$) in i^{th} stratum

A computer model (Couillard 1992) was used to calculate integrated values of solar and lunar submarine irradiance within the 400-700 nm spectral range at each station. The input

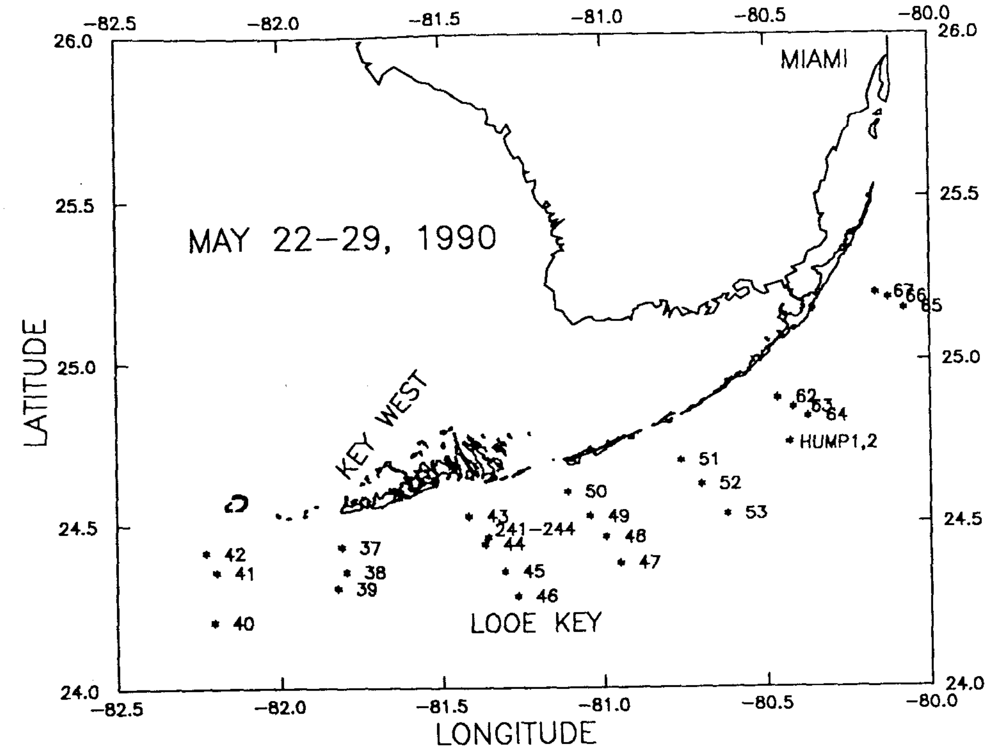

Fig. 1. MOCNESS sampling stations off the Florida Keys during SEFCAR cruise LH1.

parameters include the Greenwich Mean Time (GMT) and date, latitude and longitude of sampling, air mass type (marine or continental dominated aerosols), relative humidity, cloud cover, precipitable water vapor, mean wind speed over 24 hours, current wind speed, visibility, ozone scale height and chlorophyll-a profile for the water column. Continuous real-time chlorophyll indices were recorded by a fluorometer on the MOCNESS and calibrated to typical chlorophyll-a values for this region (D. Frazel, pers. comm.). Meteorological data were obtained from the National Weather Service records for Key West.

Computer-generated irradiance data (Wm^{-2}) were log-transformed, and selected values (2.0,1.5,1.0,0.5,0.0) were plotted against depth as one continuous 24-hr series. This series was compared to the vertical distribution of phyllosomata with Pearson correlation.

A total of 1,330 *Panulirus* spp. phyllosomata were caught almost entirely (99%) between 0-60 m. Approximately 80% were the early stages I-II, out of 11 larval stages. The depth difference between day and night C was small but statistically significant (t-test P=0.003). The night mean C was 14±4 S.E. (n=7), and day mean C was 22±9 S.E. (n=21). Diel changes in vertical distribution at both 24-hr sampling series were consistent with this overall pattern (Fig. 2).

New moon was on 24 May, 1990, and cloud cover was 70-100% for 95% of the stations. As a result, all night stations except two (H1, 65) had negligible light at the surface (Table 1). Day values ranged from ≈26-260 Wm^{-2} (≈120-1200 $\mu Em^{-2}s^{-1}$) at the surface, and decreased exponentially to near extinction at 100 m. Parabolic functions fit well to log-transformed irradiance data (Fig. 3). C of

TABLE 1

Station data and catch of Panulirus *spp. phyllosomata for SEFCAR cruise LH1 (23-29 May, 1990). Greenwich Mean Time was local time plus 4 hours. Time between sunset and sunrise is considered to be night*

Station	Latitude (decimal degree)	Longitude (decimal degree)	Date	Local Time (m-d)		Max. Sampling Depth (m)	Distance Offshore (km)	Bottom Depth (m)	catch (n)	abundance ($n \cdot 10m^{-3}$)	center of concentration (m)	irradiance at center of concentration (Wm^{-2})	irradiance at center of concentration ($\mu Em^{-2}s^{-1}$)
37	24.43	81.81	5-23	2319	night	40	5.31	57	19	16	20	0	-
38	24.36	81.80	5-23	0053	night	130	14.26	164	62	45	18	0	-
39	24.30	81.82	5-23	0322	night	200	22.26	240	30	26	13	0	-
40	24.29	82.20	5-22	1707	day	200	23.21	243	1	1	10	66.4	272.5
41	24.36	82.20	5-22	1451	day	160	13.78	181	25	21	30	42	165.4
42	24.42	82.23	5-22	1307	day	60	8.68	78	19	17	35	29.6	116.8
43	24.53	81.42	5-24	0824	day	25	3.69	36	0	0	-	-	-
44	24.44	81.37	5-24	1043	day	130	12.50	190	22	14	26	35.4	140.6
45	2436	81.31	5-24	1440	day	200	20.44	217	18	12	24	53.8	213.6
46	24.28	81.27	5-23	0841	day	160	29.97	196	14	10	16	20.1	81.2
47	24.38	80.95	5-25	1928	day	200	26.85	228	12	7	21	9	36.0
48	24.46	80.99	5-25	1706	day	190	18.04	208	14	11	11	66.2	270.8
49	24.52	81.04	5-25	1425	day	160	10.92	193	15	13	10	94.5	387.7
50	24.60	81.11	5-25	1231	day	30	2.55	41	6	5	24	49.4	197.2
51	24.69	80.76	5-26	0900	day	60	5.22	78	24	20	31	15.8	62.6
52	24.62	80.70	5-27	1028	day	185	13.31	195	53	35	17	46.3	26.3
53	24.53	80.62	5-27	1301	day	200	23.72	212	7	6	39	30.8	120.9
62	24.88	80.47	5-27	1535	day	60	4.50	67	51	42	28	44.7	177.1
63	24.86	80.42	5-27	1656	day	92	8.34	108	29	27	18	52.9	212.8
64	24.83	80.37	5-27	1848	day	150	12.48	169	93	72	13	27.1	110.1
65	25.16	80.08	5-29	2156	night	200	11.49	201	30	20	12	0	0.0
66	25.19	80.13	5-28	1959	day	125	7.42	137	268	181	19	82.3	328.1
67	25.21	80.17	5-28	1848	day	60	4.21	70	23	20	15	107	432.6
241	24.46	81.35	5-24	1225	day	160	9.53	171	11	8	21	58.1	232.0
242	24.45	81.36	5-25	2243	night	160	10.64	171	54	33	13	0	0.0
243	24.44	81.36	5-25	0031	night	160	12.23	181	26	21	10	0	0.0
244	24.46	81.36	5-24	0920	day	160	9.81	177	26	18	31	19.6	77.4
H1	24.75	80.43	5-28	2336	night	80	12.18	109	157	95	11	11.4	46.3
H2	24.80	80.43	5-28	1341	day	80	10.27	140	221	196	39	36.4	142.2

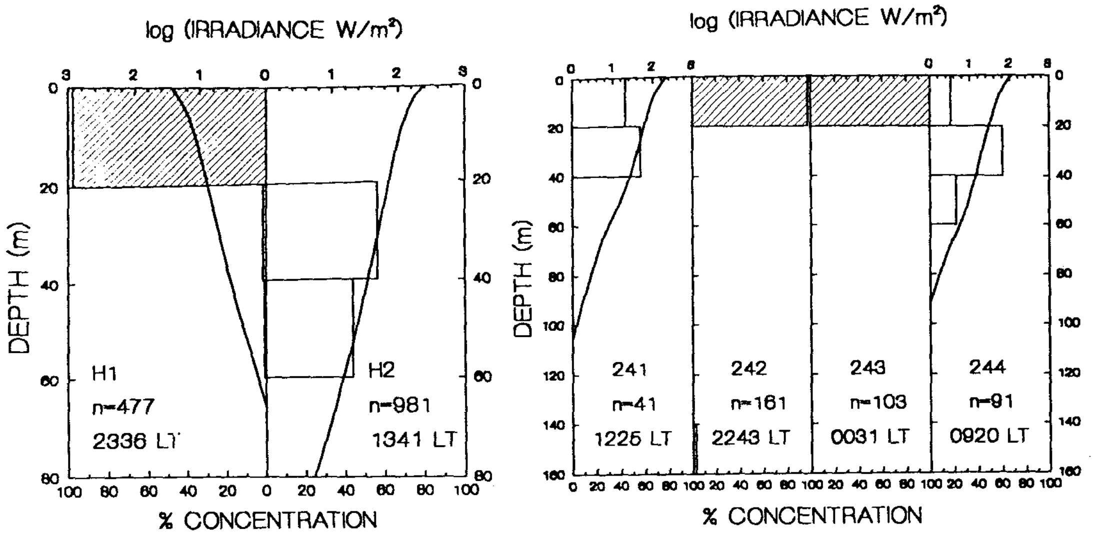

Fig. 2. Chronological series of the vertical distribution of *Panulirus* spp. phyllosomata at the H1, H2 (left) and 241-244 (right) 24-hr stations. The log-irradiance (Wm^{-2}) profiles are superimposed upon the distribution. Stations 242, 243 had negligible surface irradiance. (Shaded bars=night, blank bars=day, n=total catch per $1000m^3$ at station, LT=local time)

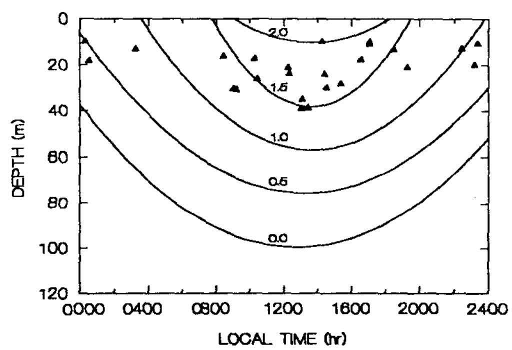

Fig. 3. Depths of isolumes of log-irradiance (Wm^{-2}) (0.0, 0.5, 1.0, 1.5, 2.0) and the center of concentration (▲) of *Panulirus* spp. phyllosomata over the diel cycle. Since mean depth of stratum was used to calculate center of concentration, the minimum depth of distribution is 10 m for the surface stratum (0-20 m).

Panulirus phyllosomata was above the depth of the 0.5 isolume (≈3 Wm^{-2}=12 $\mu Em^{-2}s^{-1}$=0.01% surface irradiance). During the day, C was above the 1.0 isolume (≈10 Wm^{-2}= 40$\mu Em^{-2}s^{-1}$= 0.05% surface irradiance). The deepest C's occurred between 0800-1600 hr in the day. Isolume contours also showed deepest penetration between these hours. However, correlation between the depth of any of the five selected isolumes and the depth of C was insignificant (Pearson r^2=0.028-0.104, P=0.166-0.553).

Rimmer and Phillips (1979) reported the DVM of *Panulirus cygnus* in association with isolumes off the west coast of Australia, which they hypothesized to facilitate the return transport of larvae to their origin. They calculated lunar irradiance at the surface with a model, whereas daylight was measured by a submarine quantum meter at 5-10 m intervals. Our irradiance data were calculated with a model, which incorporated some real-time sampling data (chlorophyll index, time, date, latitude, longitude). Isolume contours thus produced corresponded well with the characteristic diurnal pattern, despite time-points over several days' sampling being condensed into one continuous 24-hr series. This close correspondence reflects low variability in the diel set of input parameters over the temporal-spatial scale of our sampling period.

In general, we found *Panulirus* spp. phyllosomata to be between 40-400 $\mu Em^{-2}s^{-1}$. This is comparable to the general limits of 50-250 $\mu Em^{-2}s^{-1}$ for early-stage *P. cygnus* given by Rimmer and Phillips (1979), which were observed between 30-60 m during the day. They found significant interaction between lunar irradiance and the vertical distribution pattern of late- but not early-stage larvae. Concerning solar irradiance, they noted without quantification that the depth of peak density of all stages shifted in synchrony with their measured isolumes. We did not collect enough late-stage larvae for statistical comparison. In our data, there was an apparent correspondence between the depths of isolumes and vertical distribution, but statistically they were not significantly correlated. Although the visual patterns of DVM were strong at the 24-hr series, variability in depths of C were high during the day over all stations. This could result from increased susceptibility of phyllosomata to turbulence and advection if phyllosomata passively sink during the day. Given the spatial heterogeneity, the probability of finding no correlation between light and vertical distribution is high. We estimate that for α=0.05 and our sample S.E.≈7.5, Type II error $\beta\approx0.36$. Taking more samples and reducing physical heterogeneity by following a drogue during sampling would improve statistical power of the comparison. Non-linearity and the distribution of sampling time may also mask a significant correlation (Sokal and Rohlf 1981).

The relationship between light and DVM may be very complex. For example, DVM could be related to rates of change in light, activated by a lower light threshold, or there could be a phase shift in the correlation (Angel 1985). On the other hand, light may not be the sole or the most important factor in DVM. Other physical, chemical, and biological factors should be considered.

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REFERENCES

Angel, M. V. 1985. Vertical migrations in the ocean realm: possible causes and probable effects. Contrib. Mar. Sci. 27 (suppl.):45-70.

Couillard, J. T. 1992. A model of visible spectral subsurface irradiance with reference to control of vertical migration in zooplankton. M.A. Thesis, University of Miami, Coral Gables.

Rimmer, D. W. and B. F. Phillips. 1979. Diurnal migration and vertical distribution of phyllosoma larvae of the western rock lobster *Panulirus cygnus*. Mar. Biol. 54:109-124.

Sokal, R. R. and F. J. Rohlf. 1981. Biometry. 2nd ed. W. H. Freeman, New York. 859 pp.

Wiebe, P. H., K. H. Burt, S. H. Boyd and A. W. Morton. 1976. A multiple opening/closing net and environmental sensing system for sampling zooplankton. J. Mar. Res. 34:313-326.

Yeung, C. and M. F. McGowan. 1991. Differences in inshore-offshore and vertical distribution of phyllosoma larvae of *Panulirus*, *Scyllarus*, and *Scyllarides* in the Florida Keys in May-June, 1989. Bull. Mar. Sci. 49:699-714.