

## AN HYPOTHESIS ON THE LIGHT REQUIREMENTS FOR SPAWNING PENAEID SHRIMP, WITH EMPHASIS ON *PENAEUS SETIFERUS*

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(Accepted 25 April 1984)

### ABSTRACT

Wurts, W.A. and Stickney, R.R., 1984. An hypothesis on the light requirements for spawning penaeid shrimp, with emphasis on *Penaeus setiferus*. *Aquaculture*, 41: 93-98.

Using standard equations, we have concluded that the light intensities which have been used by investigators attempting to induce maturation and spawning are up to 4000 times higher than would occur over the spawning grounds of *Penaeus setiferus*, a species for which successful controlled spawning has yet to be achieved. We recommend that future attempts at captive maturation and spawning with that species be conducted at light levels of no more than  $12 \mu\text{W cm}^{-2}$  and that the intensity at which other species of shrimp are matured and spawned be examined relative to natural light levels on their spawning grounds. It is further recommended that the need for light of blue or green color be evaluated for its role as a promotor of maturation and spawning. The intent of these modifications in current spawning procedures is to eliminate the need for eyestalk ablation in captively spawned penaeid shrimp.

Viable spawns from unablated white shrimp, *Penaeus setiferus*, matured in the laboratory, have not been reported. Current methods for inducing maturation and spawning in other species of penaeid shrimp depend heavily on the technique of unilateral eyestalk ablation (Aquacop, 1975; Wear and Santiago, 1976; Santiago, 1977; Halder, 1978; Primavera, 1978; Beard and Wickins, 1980; Lawrence et al., 1980; Brown et al., 1980; Emmerson, 1980, 1983). Eyestalk ablation should be considered a stop-gap measure until less traumatic methods can be developed. Utilization of environmental rather than surgical stimulation of maturation may overcome the problems of reduced fecundity and poor egg viability which frequently follow use of the ablation technique.

Many of the problems which have led to difficulty in spawning penaeid

shrimp in the laboratory appear to relate to the fact that researchers have not faithfully reproduced natural conditions with respect to light intensity and color. To date, primary environmental control has been in terms of temperature and photoperiod.

The importance of light in controlling phytoplankton blooms in aquatic environments is widely recognized, as is the tendency of some planktonic species to key their reproductive peaks to correspond with phytoplankton blooms (Heinrich, 1962). While it has not been firmly demonstrated experimentally, there is circumstantial evidence to indicate that many marine animals, particularly those with herbivorous or omnivorous planktonic larvae, synchronize their hormonal cycles and gonadal maturation periods with those portions of the annual light cycle which promote the highest levels of primary productivity. In addition, the presence of an eyestalk mediated reproductive mechanism in shrimp emphasizes the importance of light on maturation. It is our purpose in this paper to present support for the contention that light intensity and color are keys to the induction of gonadal development in penaeid shrimp and to suggest a light intensity above which captive spawning of unablated white shrimp (*Penaeus setiferus*) may not readily occur.

Light is attenuated as it passes through sea water and it is only wavelengths in the blue and green which penetrate to appreciable depth, even in clear water. Turbidity affects light penetration as does angle of incidence. The amount of surface light reaching a given depth can be determined from the equation

$$I_z = I_0 e^{-kz}$$

where,  $I_0$  is surface light intensity;  $I_z$  is the light intensity at depth  $z$  (in meters);  $e$  is the natural logarithm; and  $k$  is the extinction coefficient. Light intensities are reported in  $\mu\text{W cm}^{-2}$ .

The extinction coefficient is related to wavelength and the level of suspended particulate matter. In clear coastal waters,  $k$  is about 0.15, while in turbid coastal waters it is around 0.46. In the highly turbid waters of many harbors and estuaries, values of  $k$  may be as high as 1.5 (Clark and Denton, 1962). In coastal waters, light in the green or yellow-green range (500--600 nm wavelength) is the least attenuated (Clark and Denton, 1962; Gross, 1972).

*P. setiferus* occur in highest concentrations at a depth of about 20 m off the Texas coast (Darnell et al., 1983), so it was that depth which was selected for evaluation of light intensity. We calculated the maximum possible light intensity at the ocean bottom in 20 m of water on a clear day at latitudes of 25° N and 30° N at solar noon on 22 June, 21 March and 22 December. Since *P. setiferus* is found close to shore, an extinction coefficient of 0.46 was adopted. We find that coefficient to be consistent with an actual value ( $k = 0.47$ ) calculated from a set of light readings obtained at 28° 59.3' N and 90° 0.5' W in the Gulf of Mexico (T.J. Bright, personal communication, 1983).

Surface light intensity was calculated for the time and dates of interest from tables presented by List (1951). The data are presented in Table I for 20 m. Of particular importance is the fact that at each latitude and date the maximum light intensity at depth  $I_z$  is less than  $12 \mu\text{W cm}^{-2}$ . If maturation actually occurs in shallow water where mature shrimp are most often taken along the Texas coast (Gallaway and Reitsema, 1981), the calculated value for 20 m may still be high due to the increased nearshore values of the extinction coefficient. It is our hypothesis that the values presented in Table I are maximum light intensities to which maturing white shrimp would be exposed. Our calculations may lead to values which are actually higher than those present over shrimp spawning grounds since the calculations assumed cloudless skies and the absence of a turbidity layer near the bottom of the water column. The calculations were also made at solar noon, when light penetration is maximum for the day. The actual value from the Gulf of Mexico obtained on 12 February 1983 at between 14.25 and 14.30 h at 15.8 m depth under 30% cloud cover was  $2.25 \mu\text{W cm}^{-2}$  (T.J. Bright, personal communication, 1983).

TABLE I

Conditions influencing light penetration and the intensity of light at 20 m depth at solar noon on three dates and two latitudes

| Date        | Latitude | Angle of sun from horizon | Surface light ( $\mu\text{W cm}^{-2}$ ) | $I_z$ ( $\mu\text{W cm}^{-2}$ ) |
|-------------|----------|---------------------------|---|---------------------------------|
| 22 December | 25° N    | 36° 33'                   | 65 171.7                                | 6.6                             |
| 22 December | 30° N    | 41° 33'                   | 56 597.7                                | 5.7                             |
| 21 March    | 25° N    | 59° 55'                   | 98 864.1                                | 10.0                            |
| 21 March    | 30° N    | 64° 55'                   | 93 513.2                                | 9.4                             |
| 22 June     | 25° N    | 83° 27'                   | 115 968.1                               | 11.7                            |
| 22 June     | 30° N    | 88° 27'                   | 115 119.8                               | 11.6                            |

When compared with light intensities reported by various investigators who have attempted to spawn penaeid shrimp in the laboratory, we find that our value is as much as 4000 times lower (Table II). Support for our value comes from the work by Chamberlain and Lawrence (1981) with *P. stylirostris* which showed that greatest spawning success was at a light level equivalent to  $13 \mu\text{W cm}^{-2}$ . No attempts were made to spawn that species at light levels between 0 and  $13 \mu\text{W cm}^{-2}$ .

If annual seasonal cycles are to be approximated in the laboratory to induce spawning in shrimp, it is important to adjust not only temperature and photoperiod, but also to adjust for seasonal differences in light intensity. As shown in Table I, light intensity is reduced by more than 40% in the winter as compared with the summer.

There is some experimental evidence to support the contention that not

only should shrimp be spawned under low light intensity, but that blue or green light should be used. Emmerson et al. (1983) demonstrated that unablated *P. indicus* grew and spawned continuously when held in a 12 h photoperiod at  $45 \mu\text{W cm}^{-2}$  under green and blue light. However, shrimp of the same species ceased spawning and lost weight when maintained under the same photoperiod in diffuse natural light of  $50 \mu\text{W cm}^{-2}$ . Spectral influences on spawning were also examined by Caillouet (1972) and Primavera (1980).

TABLE II

Light intensities calculated from reports in the literature for shrimp maturation facilities

| Shrimp species   | Light Intensity ( $\mu\text{W cm}^{-2}$ ) | Ref.   |
|--|---|--|
| <i>Penaeus merguensis</i> ,<br><i>P. japonicus</i> ,<br><i>P. aztecus</i> ,<br><i>P. semisulcatus</i> ,<br><i>P. setiferus</i> ,<br><i>Metapenaeus ensis</i> | 11597-46 387                              | Aquacop (1975);<br>Lawrence et al.<br>(1980) |
| <i>P. japonicus</i>  | 130- 544                                  | Laubier-Bonichon (1978)                      |
| <i>P. stylirostris</i> ,<br><i>P. vannamei</i>   | 0- 320                                    | Chamberlain and<br>Lawrence (1981)           |
| <i>P. indicus</i> , <i>P. monodon</i>  | 70  | Emmerson (1980, 1983)                        |
| <i>P. monodon</i>  | 39- 68                                    | Beard and Wickins (1980)                     |
| <i>P. indicus</i>  | 45- 50                                    | Emmerson et al. (1983)                       |
| <i>P. plebejus</i>   | 3- 17                                     | Kelemec and Smith (1980)                     |

Another apparently light-related phenomenon involves the lack of spawning in small tanks. Many researchers feel that only relatively large tanks can be used to spawn shrimp. Emmerson (1983) noted that unablated *P. monodon* would not spawn in tanks 2 m X 1.5 m X 0.5 m deep, even under reduced light intensity. In an earlier study, the same author (Emmerson, 1980) found that *P. indicus* held in tanks with black interiors spawned twice as frequently as those maintained in tanks with white interiors. The difference would appear to relate to the absorbance of light in black tanks as compared with reflectance in white tanks. While some shrimp species may actually require considerable space to affect mating, an argument can be made that small tanks reflect more light internally than large ones and, because of generally shallower water, may also attenuate less light. Thus, under the same surface intensities, the  $I_z$  to which the shrimp are exposed may be higher in a small tank, another reason to use tanks with dark colored interiors and to measure light intensities within tanks, rather than at the water surface.

In summary, our evaluation has demonstrated that the levels of light being utilized to spawn penaeid shrimp in the laboratory are excessively high compared with conditions on the natural spawning grounds and that the color of light being used does not simulate natural conditions. Incorporation of light intensities over spawning chambers of no more than  $12 \mu\text{W cm}^{-2}$  utilizing blue or green light may obviate the need for eyestalk ablation. This theory should, at least, be thoroughly tested by investigators who have the facilities to conduct the studies. The ultimate goal will be to eliminate the need for eyestalk ablation and to spawn shrimp on demand through manipulation of environmental conditions alone. While *P. setiferus* was used as our model, the approach may have merit in conjunction with other penaeids, other crustaceans and finfish as well.

## ACKNOWLEDGEMENTS

We would like to thank John H. Wormuth and G.A. Franceschini for their valuable assistance in directing us to the appropriate information sources with respect to surface light intensities and to light attenuation in sea water, and for their helpful comments during preparation of the manuscript. The manuscript was reviewed by George Chamberlain, whose comments and criticisms are appreciated.

## REFERENCES

- Aquacop, 1975. Maturation and spawning in captivity of penaeid shrimp: *Penaeus merguensis* de Man, *Penaeus japonicus* Bate, *Penaeus aztecus* Ives, *Metapenaeus ensis* de Hann, and *Penaeus semisulcatus* de Hann. Proc. World Maricult. Soc., 6: 123-132.
- Beard, T.W. and Wickins, J.F., 1980. Breeding of *Penaeus monodon* Fabricius in laboratory recirculating systems. Aquaculture, 20: 79-89.
- Brown, A., McVey, J.P., Scott, B.M., Williams, T.D., Middleditch, B.S. and Lawrence, A.L., 1980. Maturation and spawning of *Penaeus stylirostris* under controlled laboratory conditions. Proc. World Maricult. Soc., 11: 488-499.
- Caillouet, C.W., 1972. Ovarian maturation induced by eyestalk ablation in pink shrimp, *Penaeus duorarum* Burkenroad. Proc. World Maricult. Soc., 3: 205-225.
- Chamberlain, G.W. and Lawrence, A.L., 1981. Effect of light intensity and male and female eyestalk ablation on reproduction of *Penaeus stylirostris* and *P. vannamei*. J. World Maricult. Soc., 12: 357-372.
- Clark, G.L. and Denton, E.J., 1962. Light and animal life. In: M.N. Hill (Editor), The Sea, Vol. 1. John Wiley and Sons, New York, NY, pp. 456-468.
- Darnell, R.M., Defenbaugh, R.E. and Moore, D., 1983. Northwestern Gulf shelf bio-atlas. A study of the distribution of demersal fishes and penaeid shrimp of soft bottoms of the continental shelf from the Rio Grande to the Mississippi River delta. Open File Report 82-04, U.S. Dept. of the Interior/Minerals Manage. Serv. pp. 26-109.
- Emmerson, W.D., 1980. Induced maturation of prawn *Penaeus indicus*. Mar. Ecol. Prog. Ser., 2: 121-131.
- Emmerson, W.D., 1983. Maturation and growth of ablated and unablated *Penaeus monodon* Fabricius. Aquaculture, 32: 235-241.

- Emmerson, W.D., Hayes, D.P. and Ngonyame, M.; 1983. Growth and maturation of *Penaeus indicus* under blue and green light. S. Afr. J. Zool., 18: 71-75.
- Gallaway, B.J. and Reitsema, L.A., 1981. Shrimp and redfish studies in relation to Bryan Mound brine disposal site off Freeport, Texas. Final Report to National Marine Fisheries Service, Galveston Laboratory, Texas by LGL Ecological Research Associates, Inc., Bryan, TX, 84 pp.
- Gross, M.G., 1972. Oceanography, Prentice-Hall, Englewood Cliffs, NJ, 497 pp.
- Halder, D.D., 1978. Induced maturation and breeding of *Penaeus monodon* Fabricius under brackish water pond conditions by eyestalk ablation. Aquaculture, 15: 171-174.
- Heinrich, A.K., 1962. The life histories of plankton animals and seasonal cycles of plankton communities in the oceans. J. Cons., Cons. Int. Explor. Mer, 77: 15-24.
- Kelemec, J.A. and Smith, I.R., 1980. Induced ovarian development and spawning of *Penaeus plebejus* in a recirculating laboratory tank after unilateral eyestalk enucleation. Aquaculture, 21: 55-62.
- Laubier-Bonichon, A., 1978. Ecophysiology of reproduction in the prawn *Penaeus japonicus*: three year experiment in control conditions. Oceanologica Acta, 1: 135-150.
- Lawrence, A.L., Akamine, Y., Middleditch, B.S., Chamberlain, G. and Hutchins, D., 1980. Maturation and reproduction of *Penaeus setiferus* in captivity. Proc. World Maricult. Soc., 11: 481-487.
- List, R.J., 1951. Smithsonian Meteorological Tables. Smithsonian Institution, Washington, DC, 527 pp.
- Primavera, J.H., 1978. Induced maturation and spawning in five-month old *Penaeus monodon* Fab., by eyestalk ablation. Aquaculture, 13: 355-359.
- Primavera, J.H., 1980. Studies on broodstock of sugpo *Penaeus monodon* Fabricius and other penaeids at the SEAFDEC aquaculture department. Paper presented at the International Symposium on Coastal Aquaculture, 12-18 January, Cochin, India, 24 pp.
- Santiago, A.C., 1977. Successful spawning of cultured *Penaeus monodon* Fab. after eyestalk ablation. Aquaculture, 11: 185-196.
- Wear, R.G. and Santiago, J.A., 1976. Induction of maturity and spawning in *Penaeus monodon* by unilateral eyestalk ablation. Crustaceana, 31: 218-220.