Growth and maturation of *Penaeus indicus* under blue and green light

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The effect of light quality on the maturation, condition and growth of the penaeid prawn *Penaeus indicus* was tested by comparing dim green and blue illumination against that of diffuse natural light as a control. Initially growth and condition were depressed in all three tanks and this could be regarded as a 'settling down' period, while spawning activity decreased in the blue and green tanks, but increased in the control tank. After three to five months the growth slopes became positive under green and blue light and condition improved, though the spawning levels still remained low (consolidation phase). Spawning and condition then continued to improve with time. It appeared that once growth and condition had normalized under blue and green light, spawning activity resumed. In the control, however, both prawn condition and subsequent spawning activity declined steadily after the end of the second month and this could be explained as a final reproductive effort with decreasing condition until the condition was too low for effective spawning. Growth and maturation in *P. indicus* can thus occur simultaneously without adversely affecting prawn condition provided that both a good diet and good quality light are supplied.
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Die uitwerking van liggehalte op rypwording, kondisie en groei van die garnaal *Penaeus indicus* is getoets deur groen en blou lig met dowwe natuurlike lig as kontrole te vergelyk. Aanvanklik was groei en kondisie laer in al drie tenks. Hierdie was dus 'n aanpassingsperiode waartydens kuitskietaktiwiteit in die blou- en groenligtenks afgeneem het maar in die kontrole toegeneem het. Na drie tot vyf maande het die groeihelling onder die groen sowel as die blou lig positief geword en kondisie het verbeter alhoewel die kuitskietvlak steeds laag gebly het (konsolidasiefase). Kuitskieting en kondisie het daarna aanhoudend verbeter. Nadat groei en kondisie na normaal teruggekeer het onder groen en blou lig het kuitskietaktiwiteit weer begin. In die kontrole het kondisie en kuitskietaktiwiteit egter afgeneem na die tweede maand. Dit kan dus beskou word as 'n finale voortplantingspoging met afnemende kondisie totdat die kondisie te sleg was om kuit te skiet. Groei en rypwording in *P. indicus* kan dus saam plaasvind sonder om kondisie te verswak mits 'n goeie dieët en goeie kwaliteit lig verskaf word.
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Initial work on the maturation of *Penaeus indicus* Milne Edwards showed that laboratory-reared females larger than 39 g generally lost mass and condition, whilst females less than 39 g increased in mass and maintained condition (Emmerson 1980). It was suggested that this could have been the result of a change in nutritional requirements with size, light quantity and quality, tank size and/or handling stress. It was decided to pursue the possible effects of light on growth as Buikema (1973) found that high light intensity significantly decreased the number of non-viable eggs, undeveloped young and the abortion rate in *Daphnia pulex*, while blue light significantly increased the number of young per brood. Van Wormhoudt & Ceccaldi (1976) further showed that blue and green light stimulated growth in the shrimp *Palaemon serratus*, while red and orange light inhibited it. In association with maturation, adult littoral Penaeidae, with the exception of some metapenaeids (Wickins 1976) generally move offshore to breed in deeper water (Champion 1970; De Freitas 1980). Here the irradiance is of a lower intensity and different quality to shallow water as blue and green wavelengths penetrate oceanic waters deeper than other wavelengths (Clarke 1936; Utterback 1936; Jerlov 1970) such as red light which is rapidly attenuated according to the Lambert-Beer law (Weinberg 1976). The possible effects of green and blue light on growth and maturation were therefore investigated by attempting to approximate offshore benthic 'spawning ground' conditions in the laboratory. Caillouet (1973) similarly used blue and green light for the maturation of *Penaeus duorarum* while Kelemec & Smith (1980) used dim blue illumination to mature *Penaeus plebejus* domestically. The present experiment was designed to try to improve the growth characteristics of unablated adult *Penaeus indicus* held for maturation purposes, without affecting reproduction.

Material and Methods

Three circular, temperature-controlled 8000 ℓ (2,8 m diameter) glass fibre tanks (Figure 1) were used as holding vessels, two of which were situated in a darkened laboratory while the third (control Tank 3) was situated outside the laboratory with a lid. One of the laboratory tanks was supplied with five overhead green (Tank 1) and the other with similar blue (Tank 2) floodlights. Additionally 100 cm blue or green perspex discs were suspended below each floodlight

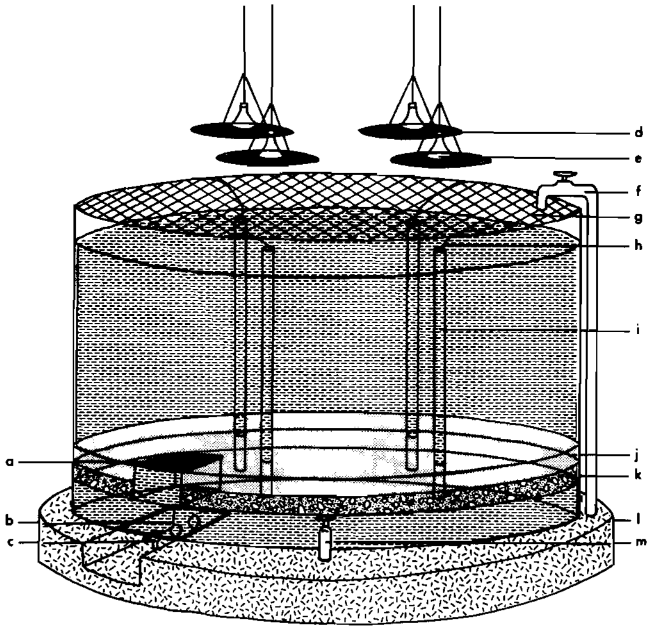

Figure 1 Holding tank for *P. indicus* maturation: a) coloured perspex cover; b) clear polycarbonate basal panel; c) basal observational illumination; d) coloured perspex discs; e) coloured floodlights; f) fresh seawater tap; g) plastic mesh cover; h) air pipe; i) airlift pipe; j) sand; k) crushed stone; l) concrete plinth; m) drainage tap.

to yield wavelength peaks at 480 and 510 nm respectively and substrate surface irradiances of 45 μW cm^{-2}. Lighting was controlled by a timer set for a 12-h photoperiod with half an hour increase and decrease to and from the set intensity respectively. The substrate surface irradiance was similar for Tank 3 (50 μW cm^{-2}). The tanks were constructed with a drilled false fibreglass bottom which supported a layer of crushed stone and sand (Figure 1), while four 50 mm ID upstand airlift pipes insured a complete water turnover approximately every 7 h. A clear panel on the base of each tank with a tight-fitting green, blue or opaque white perspex window on the false bottom allowed basal lighting to be used for ovary staging.

Twelve different-sized adult *Penaeus indicus* females and eight adult males trawled from the Tugela Bank on the Natal north coast, South Africa (Figure 2), were introduced into

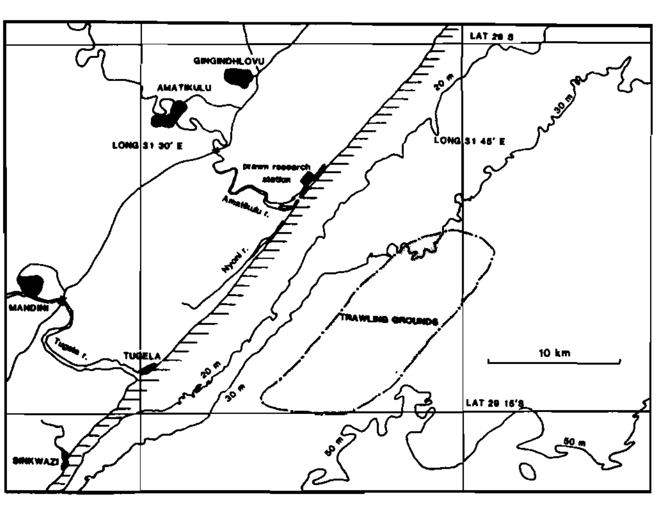

Figure 2 Map showing the position of the trawling grounds on the Tugela Bank for gravid *P. indicus.*

each tank. Females were code marked to facilitate daily individual ovary staging (Figure 3). As it was considered that handling stress may have previously affected growth (Menz & Blake 1980) animals were left to spawn freely in the tank and were only removed once a month for weighing and for periodic re-marking. Spawns therefore had to be assessed by daily observations of ovary progress and the presence of eggs and nauplii in the water. Occasional mortalities were immediately replaced with fresh animals.

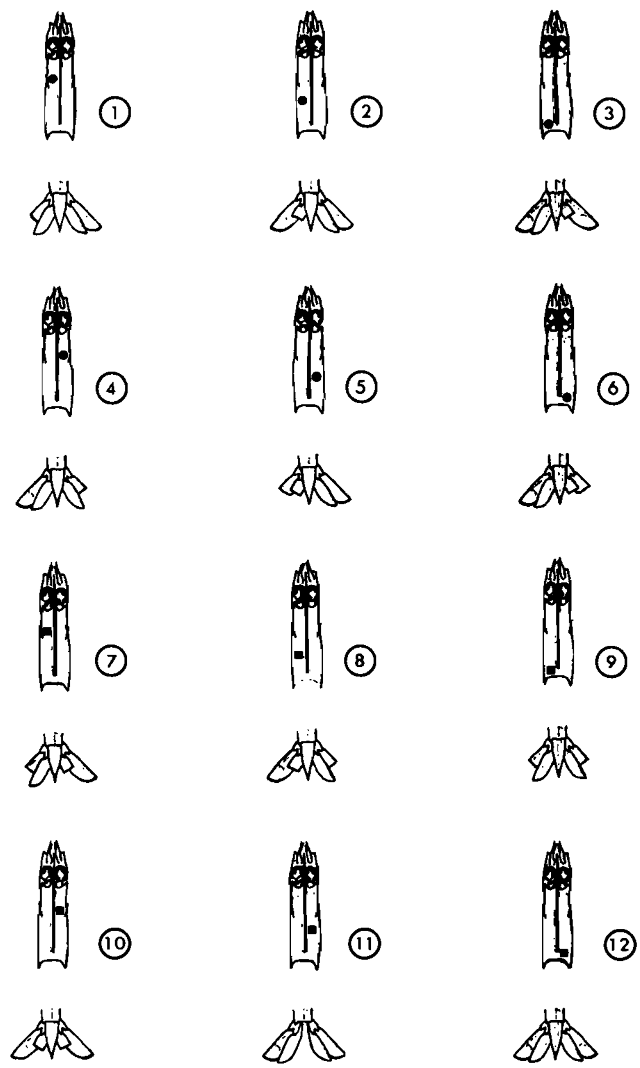

Figure 3 The code-marking system used to identify maturing females of *P. indicus*.

Tanks were covered with 20 mm diameter plastic mesh to prevent the animals from jumping out and yet still allow light to enter. The diet was changed from that used previously (Emmerson 1980) to obtain a better linolenic/linoleic acid balance (Shewbart, Mies & Ludwig 1973; Colvin 1976; New 1976; Jones, Kanazawa & Ono 1979; Read 1981). Prawns were fed twice daily on a dry pellet (Table 1) at a rate of 2,5% and fresh-frozen prawn at approximately 3,5% of total fresh mass. After two months dried *Enteromorpha* sp. was included in the diet at 9,1% as it was readily grazed by *P. indicus* in outdoor ponds (Table 1). Many successful Japanese pellets contain seaweed, e.g. Higashi Maru, and *Enteromorpha* is also a good protein source (17,4% of dry

Table 1 Improved maturation diet formulated for *P. indicus* (bound with 10% PVA), before inclusion of *Enteromorpha* sp. (A) and after the inclusion (B)

Ingredient	A %	B %
Fish meal	40	36,5
Prawn meal	30	27,3
Flour	15	13,6
Mineral mix	3	2,7
Vitamin mix	3	2,7
Choline chloride	2	1,8
Cholesterol	2	1,8
Anchovy oil	2	1,8
Sunflower oil	2	1,8
Linseed oil	1	0,9
Dried *Enteromorpha* sp.	–	9,1
	100	100,0

mass by Kjeldahl N × 6,25). The condition factor (Kn) was calculated as described previously (Emmerson 1980). Water exchange was 30% every 2 days. Temperature, pH, salinity, oxygen, total ammonia (Solorzano 1969) and nitrite (Bendschneider & Robinson 1952) were monitored daily.

Results and Discussion

Temperature (24,1 – 26,6 °C), pH (7,8 – 8,1), oxygen (6,2 – 6,8 mg l^{-1}), total ammonia (0,034 – 0,038 mg l^{-1}) and nitrate (0,034 – 0,039 mg l^{-1}) remained constant.

During the first month growth was depressed in all three tanks (Figure 4). Nil growth points were at 30 g and growth slopes (β) were all negative (Table 2). The relative condition factors (Kn) also declined. This was previously shown to occur during the first month after introduction into maturation tanks and was attributed to a 'settling down' period (Emmerson 1980). However, after the second month, females in Tank 1 (green) all gained mass (even above 39 g initial mass) with a slight increase in Kn, whereas the growth slopes in Tank 2 (blue) and Tank 3 (control) remained unchanged (Kn = 0,882 and 0,894 respectively). At the end of Month 3, the growth slope of Tank 1 reversed positively, with a concomitant slight increase in Kn (0,921), while in Tanks 2 and 3 the slope was still negative although the nil points had increased to 38 g and 39 g respectively. The condition of the Tank 2 females began to improve (Kn = 0,907), whereas it declined in Tank 3 (Kn = 0,887). By the end of Month 4, all the animals under blue or green light conditions (Tank 1 and 2) had gained mass, especially the smaller females under blue light, whereas growth in the control females (diffuse light) remained unchanged with a negative slope. Although growth was positive in Tanks 1 and 2, the slope in Tank 2 was still negative (Figure 4). Condition factors in Tanks 1 and 2 had increased from the previous months, but average condition in the control decreased further to a Kn of 0,87 (Table 2). Although females under blue and green light increased in mass after Month 4, it was only after the fifth month that the growth slope under blue light became positive and the growth characteristics of Tanks 1 and 2 became approximately similar, with good

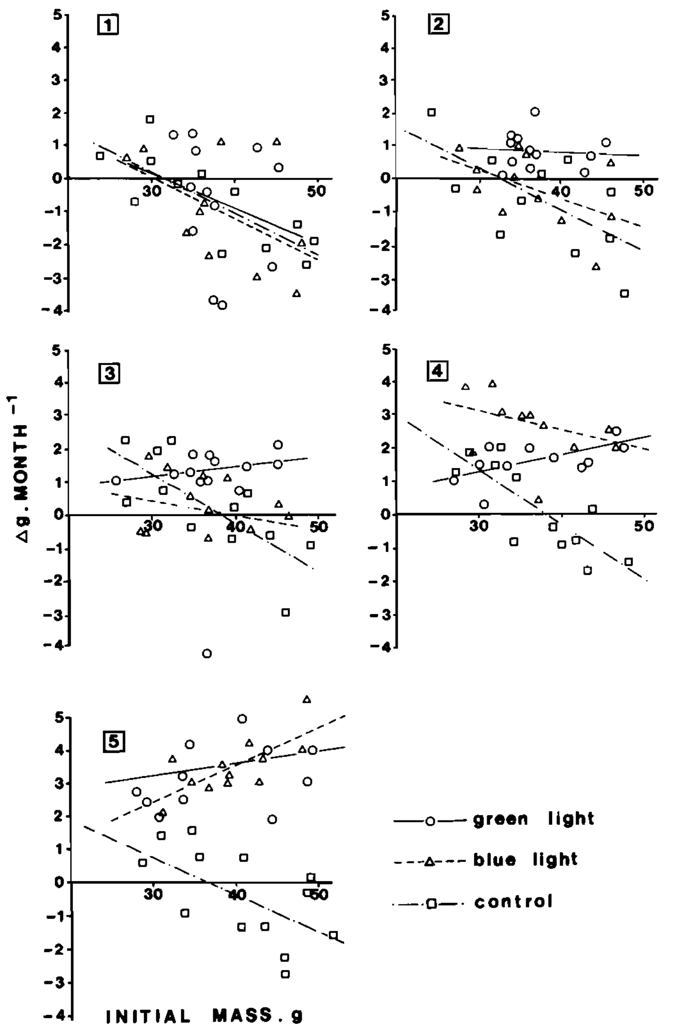

Figure 4 The relationship between initial mass (g) and change in mass (Δg month^{-1}) for adult *P. indicus* females held under blue, green and diffuse natural light (control) over a 5-month period. (Numbers in squares = months.)

condition factors (Kn = 0,93 and 0,927 respectively). By contrast the control slope remained unchanged and the condition decreased to a very low level of Kn = 0,821. Correlation coefficients (*r* values; Table 2) were low owing to scatter and slope reversal.

Approximate average spawns per female per month for the tanks may be seen in Table 2. Assessment was difficult owing to infertile or simultaneous spawns. Sudden ovary depletion immediately prior to a moult was regarded as a resorption and not a spawn. Average spawns ranged from 0,1 – 1,75 spawns per female per month in Tank 1; 0,5 – 1,3 spawns per female per month in Tank 2; to 0,2 – 2,3 spawns per female per month in Tank 3. In Tanks 1 and 2, spawns decreased from Month 1 to Month 3 and then increased again up to Month 5, and appeared to be associated with growth, whereas in the control, spawns increased to the end of the second month and then rapidly decreased with a decline in condition. Initially, good spawning was associated with poor growth characteristics (nil point and slope) and as growth improved spawning decreased accordingly. However, during the last two months (4 and 5) and especially the last month, spawning activity increased concomitantly with the good somatic growth and regained condition

Table 2 Nil growth points, growth slopes, correlation coefficients (*r*) and average spawns per female per month for adult *P. indicus* held under green, blue and diffuse natural light (control) for 5 months

Month	Nil growth point (g)	Slope (β)	*r*	$\bar{x}$ Spawns female^{-1} month^{-1}	Kn
Tank 1 (Green)					
0					0,906
1	30	−0,1	0,23	0,67	0,890
2	107	−0,01	0,051	0,3	0,913
3	–	0,01	0,404	0,1	0,921
4	–	0,04	0,536	0,5	0,930
5	–	0,034	0,199	1,75	0,927
Tank 2 (Blue)					
0					0,910
1	30	−0,12	0,525	1,25	0,878
2	34	−0,08	0,488	0,6	0,882
3	38	−0,039	0,265	0,5	0,907
4	113	−0,034	0,305	0,7	0,923
5	–	0,14	0,733	1,3	0,930
Tank 3 (control)					
0					0,92
1	32	−0,122	0,787	1,9	0,899
2	33	−0,123	0,647	2,3	0,894
3	39	−0,147	0,748	1,6	0,887
4	38	−0,167	0,817	0,3	0,870
5	37	−0,111	0,562	0,2	0,821

(Tanks 1 and 2). Growth and condition decreased monthly in the control and spawning could be explained as a final reproductive effort with decreasing condition until the condition was too low for effective spawning (Kn < 0,88).

It appeared therefore that initially females lost mass until they acclimated to their holding conditions, while spawning activity was stimulated owing to the low light intensities. Months 2 and 3 could then be regarded as a refractory period for the blue and green light tanks, during which time growth normalization occurred. This occurred quicker under green light than blue light (2 vs 4 months respectively), while growth never normalized in the control tank. Once growth had normalized in Tanks 1 and 2, spawning activity resumed.

It was also noted in Tank 2 that during the first three months, the prawns were active and continually swam around the tank perimeter. This increased activity could possibly explain the observed lag in growth response during this period as more energy could have been expended on movement than on growth. Le Reste (1970) has indicated that *P. indicus* is more active between 18 h and 23 h and perhaps blue light elicits this activity. More recently, Möller & Naylor (1980) have shown that the locomotory rhythm of *Nephrops norvegicus* in the laboratory appears to be controlled by absolute irradiance thresholds, previous light history and food availability. These three factors were equal for *P. indicus* in tanks. However, the effective irradiances may have differed owing to wavelength perception differences.

The algae in the diet probably had the effect of improving the general quality and acceptability of the diet as it forms part of the natural food of *P. indicus.* Gopalakrishnan (1952) found that vegetable matter, particularly algae, formed a large proportion of the stomach contents in *P. indicus*. New (1976) has described a prawn diet containing seaweed meal at 5% inclusion, while Forster & Gabbot (1971) showed that cellulose is partly digested by shrimp, indicating that they have the ability to utilize marine algae in their diet. The finding by Middleditch, Missler, Ward, McVey, Brown & Lawrence (1979) and Middleditch, Missler, Hines, Chang, McVey, Brown & Lawrence (1980), that certain C_{20} and C_{22} polyunsaturated fatty acids are required in the diets of penaeid shrimp to promote ovarian maturation is important as the maturation diet (Table 1) was changed to include both the families of essential fatty acids (linoleic and linolenic) in a ratio that was proven to be superior (Read 1981).

It was evident that overstimulation of the maturation process was encountered during this (control) and previous work (Emmerson 1980). As there was no difference in diet or holding conditions, the observed differences in the control tank can only be attributed to differences in light quality. Handling stress was eliminated as a factor as the growth characteristics in the control were not improved despite not being handled. As light quality has been shown to affect fecundity and growth in other crustaceans (Buikema 1973; Van Wormhoudt & Ceccaldi 1976), it is not surprising that the same has been found for *P. indicus.*

It appears, therefore, that a healthy female can both spawn (1,3 to 1,75 times per female per month) and still remain in a good condition (Kn = 0,927 to 0,93; Table 2). A spawning rate of once per female per month for wild *P. indicus* thus remains a reasonable projection, with a female spawning naturally at least 7 – 9 times per lifetime (Emmerson 1980).

In conclusion, it appears that growth and maturation can occur simultaneously without adversely affecting the prawns' condition, provided that both a good diet and wavelength are supplied. Van Wormhoudt & Ceccaldi (1976) showed that different wavelengths affect enzymatic activity, thus affecting digestibility, assimilation and hence growth. The growth characteristics of adult *P. indicus* females held for maturation purposes were therefore improved using blue and green light. Although the tanks and food were the same, the growth response was different under differing light regimes, thus illustrating the positive role of light quality on growth and maturation. A number of monochromatic wavelengths and light mixes can now be tested on growth and maturation in prawns to further improve the growth responses.

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