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Growth rhythms in the shrimp *Penaeus vannamei* and *P. schmitti*

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Abstract. Growth increments of the penaeid shrimp *Penaeus vannamel* (Boone) and *P. schmitti* (Burkenroad) grown in commercial production ponds in Ecuador and Colombia were measured over a 4 mo period between October 1987 and January 1988. *P. vannamel* grown from wild caught seed in Ecuadorian ponds exhibited a growth rhythm which significantly coincided with lunar phases. Growth increments of at least 1 gwk^{-1} occurred around a new and full moon, while growth increments of less than 1 gwk^{-1} occurred during first and last quarters. *P. vannamel* transported from Ecuador as nauplii, raised in Colombian hatcheries and on grown in Colombian ponds exhibited a cyclic pattern in wet weight increments but no correlation to lunar cycles was observed. *P. schmitti* showed no cyclic pattern in growth. The two species under consideration are indigenous to two different, and quite unique areas displaying different environmental characteristics. The link between the growth pattern, biological and lunar cycles is discussed.

Introduction

There are numerous examples of marine organisms which exhibit spontaneous physiological and behavioral rhythms which are synchronised closely to different environmental cycles (see review by Neumann 1981). Many papers report the existence of an endogenous physiological pacemaker system which generates approximate periodicity adjusted by local environmental cues, or "zeitgebers" (McDowell 1969, Enright 1972, DeCoursey 1983, Natarajan 1989a, b). While some studies have examined activity rhythms in Penaeid shrimp, *Penaeus duorarum* (Fuss 1964, Fuss and Ogren 1966), *P. merquiensis* (Hindley 1975), *P. semisulcatus* and *P. monodon* (Moller and Jones 1975) and *P. indicus* (Natarajan 1989a, b), they have not explored the possibility of growth cycles following rhythmic patterns. The present study introduces the possibility of a link between growth cycles in *P. vannamei* and *P. schmitti* and lunar phase, and that this is a facet of the regions to which they are indigenous.

Materials and methods

In Ecuador a 110-ha shrimp farm, located about 50 miles from Guayaquil, was used as a study site. Four rectangular ponds of approximately 10 ha and 1 m in depth were stocked with *Penaeus vannamei* juveniles at 75 000 ha^{-1}. All juveniles were from wild caught larvae held for 30 d in nursery ponds. During the study, early morning (before 08:00 hrs) temperature was 28 ± 2 °C and salinity was 9 ± 1‰.

In Colombia, a 60-ha shrimp farm, located about 60 miles from Cartagena, was used as a study site. Five ponds, of various shapes, ranging in size from 0.5 to 4.8 ha and 1 to 1.5 m in depth were studied. Three ponds were stocked with *Penaeus schmitti* juveniles at about 35 000 ha^{-1} while the other two ponds were stocked with *P. vannamei* juveniles at about 75 000 ha^{-1}. All juveniles were laboratory raised from nauplii spawned by wild caught gravid females. In the case of *P. vannamei*, the nauplii were flown from the Pacific coast, while *P. schmitti* were locally caught and spawned on site. During the study, early morning (before 08:00 hrs) temperatures averaged 29 ± 2 °C, and salinity was 34 ± 0.5‰.

Between 100 and 500 shrimp were sampled weekly using cast nets both from the banks and from boats. Samples were pooled and average wet weights were calculated, these being used for the calculations of weekly weight increments. These values were plotted against time and tabulated according to the frequency with which a growth increment of greater than or equal to 1 g wk^{-1} were observed. This data was then assessed using the Chi-squared "Goodness of Fit" test after Williams (1979), to examine the hypothesis that the frequency with which the observations fell into the classificatory groups of the four quarters of the lunar cycle showed agreement with the Poisson distribution. This in turn would suggest that the increments in the shrimps growth cycle were not in phase with the lunar cycle, and evidence for the possibility of a link between the two was insufficient.

Results

The results for the shrimp *Penaeus vannamei* grown in both Ecuador (Fig. 1–4) and Colombia (Fig. 5 and 6) display a repeated cycle of large and small wet weight increments over the culture period (approximately 0.2 to 20.0 g). The shrimp *P. schmitti* grown in Colombia, in some cases, shows a pattern composed of gradually increasing increments up to the sixth week of culture, fol-

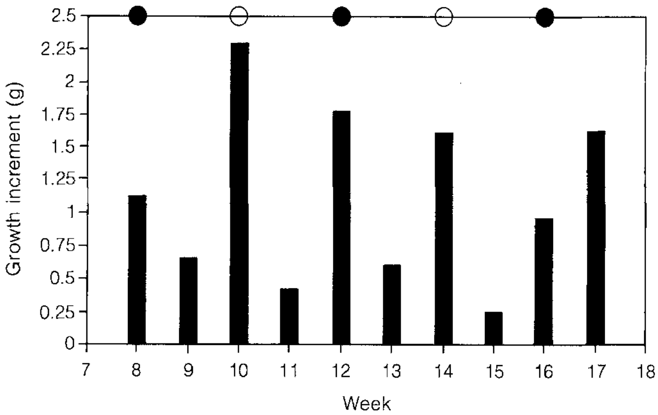

Fig. 1. *Penaeus vannamei.* Variation in growth increment of shrimp grown in Ecuadorian ponds (pond E03) with reference to lunar cycle (o: full moon; •: new moon)

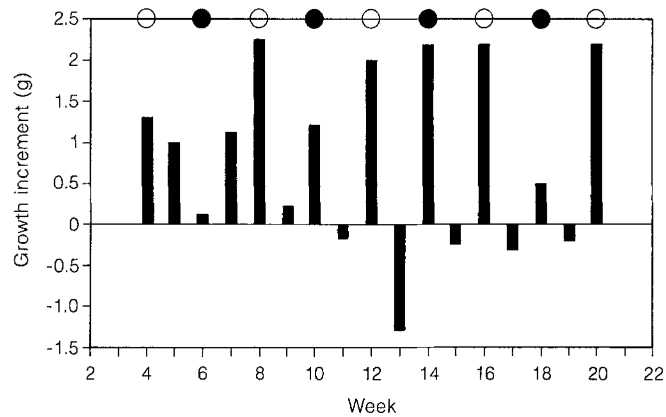

Fig. 4. *Penaeus vannamei.* Variation in growth increment of shrimp grown in Ecuadorian ponds (pond E08) with reference to lunar cycle (o: full moon, •: new moon)

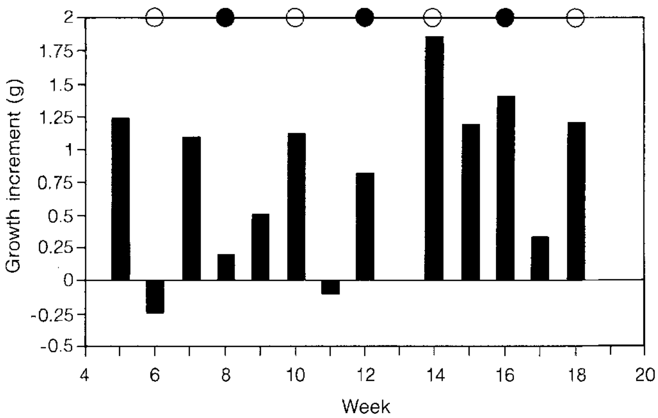

Fig. 2. *Penaeus vannamei.* Variation in growth increment of shrimp grown in Ecuadorian ponds (pond E05) with reference to lunar cycle (o: full moon; •: new moon)

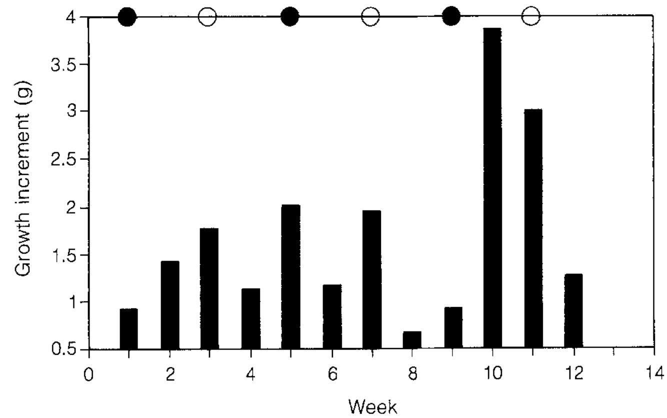

Fig. 5. *Penaeus vannamei.* Variation in growth increment of shrimp grown in Colombian ponds (pond C16) with reference to lunar cycle (o: full moon, •: new moon)

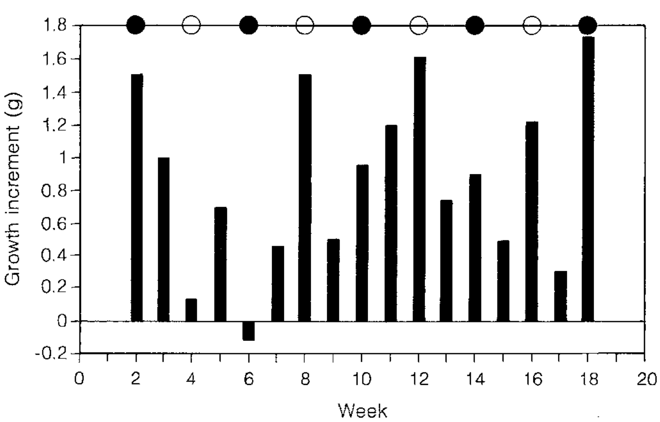

Fig. 3. *Penaeus vannamei.* Variation in growth increment of shrimp grown in Ecuadorian ponds (pond E04) with reference to lunar cycle (o: full moon; •: new moon)

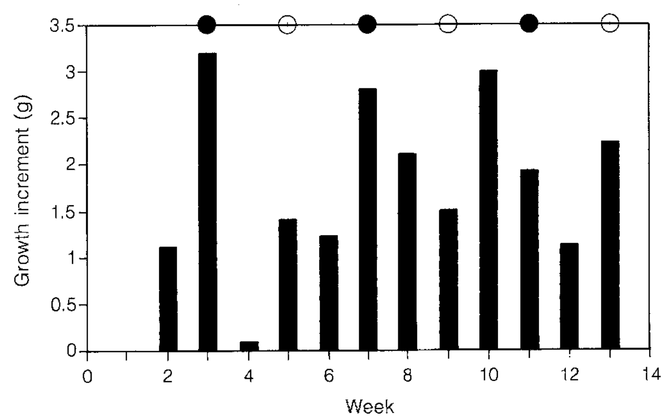

Fig. 6. *Penaeus vannamei.* Variation in growth increment of shrimp grown in Colombian ponds (pond C05) with reference to lunar cycle (o: full moon, •: new moon)

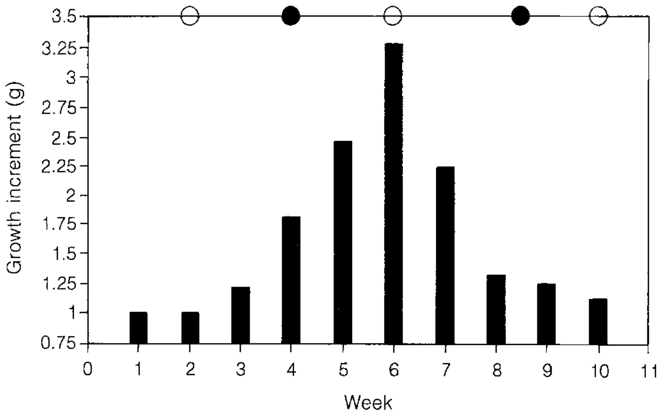

Fig. 7. *Penaeus schmitti.* Variation in growth increment of shrimp grown in Colombian ponds (pond C13) with reference to lunar cycle (o: full moon, •: new moon)

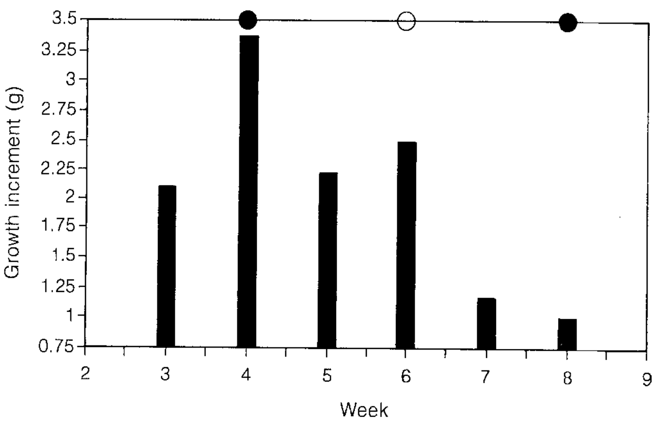

Fig. 8. *Penaeus schmitti.* Variation in growth increment of shrimp grown in Colombian ponds (pond C01) with reference to lunar cycle (o: full moon, •: new moon)

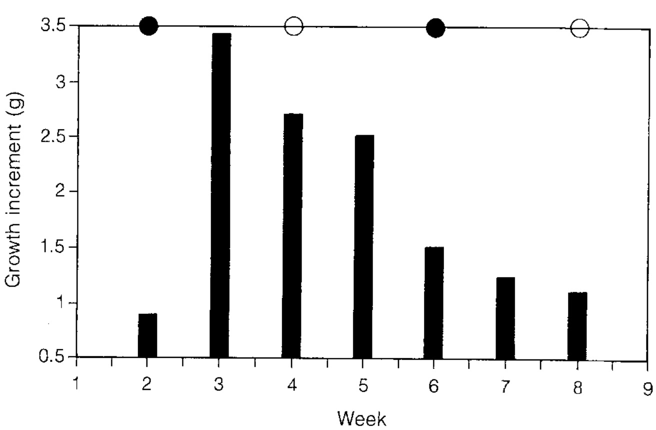

Fig. 9. *Penaeus schmitti.* Variation in growth increment of shrimp grown in Colombian ponds (pond C08) with reference to lunar cycle (o: full moon, •: new moon)

Table 1. *Penaeus vannamei.* Incidence of wet weight increments greater than or equal to 1 g wk^{-1} in the growth of the shrimp stocked in Ecuadorian ponds. $\chi^2 = 8.0$; $p < 0.05$

Pond no.	Full moon	Third quarter moon	New moon	First quarter moon
E03	2	0	2	1
E05	3	2	1	1
E04	3	0	2	2
E08	5	1	2	1
Totals	13	3	7	5

Table 2. *Penaeus vannamei.* Incidence of wet weight increments greater than or equal to 1 g wk^{-1} in the growth of the shrimp stocked in Colombian ponds. $\chi^2 = 0.4$; $p > 0.05$

Pond no.	Full moon	Third quarter moon	New moon	First quarter moon
C016	3	2	1	3
C05	3	3	3	2
Totals	6	5	4	5

Table 3. *Penaeus schmitti.* Incidence of wet weight increments greater than or equal to 1 g wk^{-1} in the growth of the shrimp stocked in Colombian ponds. $\chi^2 = 0.18$; $p > 0.05$

Pond no.	Full moon	Third quarter moon	New moon	First quarter moon
C13	3	2	2	3
C01	1	2	2	1
C08	2	1	1	2
Totals	6	5	5	6

lowed by a drop in the incremental growth (Fig. 7, 8 and 9) over the culture period (approximately 0.2 to 17 g).

The statistical analysis of the growth patterns indicate that the shrimp *Penaeus vannamei* grown in Ecuador show a significant ($p < 0.05$) relationship with the lunar cycle (Table 1), with wet weight increments of greater than or equal to 1 g wk^{-1} occurring during new and full moons, while growth of less than 1 g wk^{-1} occurred during first and last quarters. The statistical analysis for *P. vannamei* grown in Colombian ponds (Table 2) indicates that, despite intermittent large and small wet weight increments, no significant relationship ($p > 0.05$) exists between the periodicity of these increments and the lunar cycle. Similarly, statistical analysis for the shrimp *P. schmitti* grown in Colombian ponds (Table 3) confirms the absence of any relationship ($p > 0.05$) between the incremental growth observed and the lunar cycle.

Discussion

Previous observation suggests that the shrimp *Penaeus vannamei* grown in aquaculture ponds, both in Ecuador (Griffith personal observation) and in Colombia (Wigglesworth personal observation) displays an activity rhythm similar to that observed for *P. semisulcatus* and *P. monodon* (Moller and Jones 1975), *P. merguiensis* (Hindley 1975), *P. indicus* and *P. monodon* (Natarajan 1989 a). The present study indicates that *P. vannamei*, of wild post larval origin, grown in Ecuadorian ponds exhibits rhythmic variation in their incremental growth which is related closely to the lunar cycle. However, the shrimp *P. vannamei* grown in Colombian ponds, while displaying cyclical growth patterns, shows no relationship with lunar phase. The fact that *P. vannamei* in the Ecuadorian ponds in this study came from the wild, would have allowed for previous exposure to an, as yet unknown, entraining cue or zeitgeber, such as salinity or temperature (Natarajan 1989 b), or other unidentified stimuli, which may account for the observed relationship between growth and lunar cycle. Conversely, the lack of any synchronicity in the shrimp grown in the Colombian ponds may be attributable to the fact that they were never exposed to a zeitgeber, since they were grown in a hatchery prior to pond stocking. Thus, while it has not been categorically proven, the data suggests that the growth rhythm may in fact be endogenous or genetically conferred, without the environmental phasing cue (Naylor 1976).

Genetic transfer of rhythmicity has some basis in the literature, beginning with the work of Naylor with *Carcinus maenas* (Naylor 1958, Williams and Naylor 1967). More recently Konopku (1981) reported transmission of pupal ecdysial rhythm from mother to offspring of the Queensland fruitfly, *Dacus sp.* The implication of a genetically encoded rhythm is that it confers some benefit on the offspring. In the case of *Penaeus vannamei* this may reduce cannibalism between cohorts by separating generations by approximately 14 d, which is similar to the time taken for post-larval *P. vannamei* to reach the coastal nursery areas after being spawned offshore. This is analogous to Raekas (1976) "Selfish Herd" hypothesis used to explain synchronous moulting in stomatopods, whereby the greater proportion of the population is partially incapacitated at the same time which reduces cannibalism. This is supported by observations in the hatcheries, where *P. vannamei* larvae are more prone to cannibalise younger larval stages than equivalent stages when starved (Griffith personal observation).

For *Penaeus schmitti*, the lack of an endogenous rhythmicity in their growth rates is surprising, but may be attributable to a combination of two factors, one biological, and the other environmental. Firstly, gravid females are observed to spawn close to, or within coastal nursery areas, (Wigglesworth personal observation), and this may eliminate any need for cohort separation prior to arriving at the nursery areas. Secondly, tidal amplitudes within the locale of the Caribbean site are small (± 0.5 m) (Foster 1987) while those associated with the Pacific site are much larger (± 4.0 m) (Armada del Ecuador Instituto Oceanografico 1992), which, along with the fact that their periodicity is semidiurnal, contributes to making Caribbean tides rather unpredictable (Glynn 1972). In addition to this, the migration of the Inter Tropical Convergence Zone, bringing onshore winds and affecting tidal cycles (Glynn 1972, Foster 1987) means that the region is one in which potential zeitgebers may be cloaked by "environmental noise". The confirmed absence of any biorhythm's in a Caribbean faunal group as compared to a similar faunal group in the Pacific supports such a hypothesis (Foster 1987); in the Sergeant Major Damselfish *Abudefduf saxatilis* and *A. troschelii* the Caribbean species were shown to spawn throughout the lunar month with no periodicity, while in the Pacific species spawning occurred repeatedly within 9 d of a new moon.

The existence of lunar rhythmicity in *Penaeus vannamei* has long been accepted in Ecuador from observation of moulting cycles and activity rhythms in aquaculture ponds, and its monitoring is economically important since soft shrimp result in high processing losses after harvest. The existence of such a cycle is supported by observations of moult synchronicity in some penaeids (Shigueno 1975, Boddeke et al. 1978, Apud et al. 1983, Robertson et al. 1987). The apparent lack of such a rhythm in *P. schmitti* may be similarly important to its aquaculture potential in countries where this species is indigenous, as it may explain the relatively poor performance at high culture densities as being, in some part, due to elevated cannibalism during the critical ecdysis and early postmoult stages occurring continually throughout the culture cycle. These preliminary observations have important implications for aquaculture ventures for which potential economic losses through cannibalism and harvesting of moulting shrimp (Robertson et al. 1987) could amount to substantial losses.

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