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Lunar Periodicity of Larval Release by Pocilloporid Corals in Southern Taiwan

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Tung-Yung Fan, Jan-Jung Li, Sheng-Xian Ie and Lee-Shing Fang (2002) Lunar periodicity of larval release by pocilloporid corals in southern Taiwan. *Zoological Studies* **41**(3): 288-294. Lunar patterns of larval release by 3 brooding corals, *Seriatopora hystrix*, *Pocillopora damicornis*, and *Stylophora pistillata*, in southern Taiwan were investigated. Corals were collected and maintained in outdoor, flow-through systems to quantify nightly release of larvae. Planulation of *S. hystrix* and *P. damicornis* revealed a well-defined lunar pattern with planulae being released during the new moon and 1st quarter. Planulation of *S. pistillata* occurred throughout the lunar phase, but more planulae were released in the 2nd-quarter moon phase. It is likely that the lunar periodicity in planulation of the 3 pocilloporid coral species is a result of lunar periodicity in gamete and larval development. Larvae of *S. hystrix* and *S. pistillata* released later had higher rates of settlement within 24 h on plastic petri dishes. Based on the reproduction and settlement information available, it would be practical to obtain a large number of competent planulae, seed them on suitable substrata, and then transfer them to reefs for restoring damaged coral populations and communities. http://www.sinica.edu.tw/zool/zoolstud/41.3/288.pdf

Key words: Coral, Planulation, Lunar cycle, Settlement.

Reef corals of the Pocilloporidae are widely distributed and are important frame-building species on reef flats of many Indo-Pacific coral reefs (Glynn 1976, Loya 1976, Veron 1986). They are also the major pioneer species in the succession of coral communities as well as being the most-successful colonizers during the recovery of disturbed coral reefs (Grigg and Maragos 1974, Loya 1976, Wallace 1985). Data on the reproductive characteristics of these corals provide valuable information to better understand the dynamics and recovery of coral communities.

The timing of reproduction in reef corals has received considerable attention in recent years. Many brooding corals, whose eggs are fertilized internally and fully developed larvae are released in a process known as planulation, have several reproductive cycles throughout the year and usually with monthly periodicity (Harrison and Wallace 1990, Richmond and Hunter 1990, Tanner 1996). Several brooding species have been observed to release larvae with some sort of lunar periodicity (Harriott 1983, Szmant-Froelich et al. 1985, Tanner 1996), yet reproductive periodicity may vary with latitudinal location (Stimson 1978, Rinkevich and Loya 1979, Richmond and Jokiel 1984).

Lunar periodicity of planula release in scleractinian corals of the family Pocilloporidae has been widely studied throughout the Indo-Pacific (Atoda 1947a b 1951, Rinkevich and Loya 1979, Harriott 1983, Richmond and Jokiel 1984, Jokiel 1985, Stoddart and Black 1985, Fan and Dai 1996, Tanner 1996). While many studies have documented the lunar periodicity of planula release by pocilloporid corals, patterns are not consistent

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among different geographical localities. Further studies at different locations will help confirm the timing of planula release and determine the reasons for lunar periodicity in planulation (Harrison and Wallace 1990, Tanner 1996).

Three pocilloporid coral species, *Seriatopora hystrix*, *Pocillopora damicornis*, and *Stylophora pistillata*, are abundant in shallow waters on fringing reefs of southern Taiwan (Dai 1989). Since coral communities in shallow waters are degraded most severely by human and natural disturbances, reproductive information on these shallow-water species is important to understand the potential for their recruitment and recovery, as well as to conduct restoration on damaged coral reefs.

In this study, we used larvae collectors in aquaria to examine the lunar periodicity of larval release for the 3 pocilloporid species in southern Taiwan. The settlement behavior of their larvae was also investigated for the future applications using sexual recruits to restore damaged reefs.

MATERIALS AND METHODS

Eight colonies of each of the 3 pocilloporid coral species, *Seriatopora hystrix* (9.0 to 18.5 cm in diameter), *Pocillopora damicornis* (6.6 to 14.3 cm in diameter), and *Stylophora pistillata* (11.5 to 19.0 cm in diameter), were collected in Nanwan Bay, southern Taiwan (21°55'N, 120°45'E) on 19 April 2000. Intact colonies were removed from the reef using a hammer and chisel. Colonies were transported to the Husbandry Center in the National Museum of Marine Biology and Aquarium and were maintained in outdoor flow-through seawater systems. Seawater was filtered by sand filters. Each colony was placed in a separate aquarium to allow it to planulate without interference. The outflow of each aquarium passed through a sieve consisting of a plankton net, with a mesh size of 200 μm, to trap any larvae that were released. The number of larvae released by each colony was counted every morning since planulation occurs mostly at night (Harrison and Wallace 1990). Counts were made from 20 April (lunar day 16) to 18 May (lunar day 15) 2000, except on 23 and 30 April. The length and width of larvae were measured using a micrometer eyepiece.

To determine the settlement rate of planulae of the 3 coral species, the same method was used to collect planulae from 30 December 2000 to 10 January 2001. One to 3 replicates of 10 newly released planulae were placed in plastic petri dishes with natural seawater to 1-cm depth. Seawater in the petri dishes was not aerated or changed during the course of the monitoring period to avoid disturbance. The petri dishes were maintained under natural temperature and photoperiod. After 24 h, settled planulae were inspected, and their numbers were counted visually. Successful settlement was judged based on attachment to the surface and flattening of the larvae.

To determine the lunar periodicity of planula release, data were analyzed according to lunar day. Rayleigh's test (Zar 1984) was used to test the null hypotheses that planula release was uniformly distributed throughout the lunar cycle. If the null hypothesis was rejected, the mean lunar day of planulation was calculated using circular statistics (Zar 1984), to determine in which phase of the moon planulation was predominant (Tanner 1996). For comparison of larval settlement, one-way ANOVA was used to detect differences.

RESULTS

Lunar cycle of larval release

Seriatopora hystrix

Planulae were released from 2 to 11 days after the new moon (lunar day 1), and planulation revealed a well-defined lunar pattern (Fig. 1). The mean lunar day of planula release was 7.2 with an angular deviation of 32.8; the clustering of planulae around this day was very significant (Table 1). The peak of number of planulae released (n = 5138) occurred on lunar day 6 (Fig. 1), although most (n = 4350) were contributed by only 1 colony. The maximum number of larvae released by a single colony (mean diameter, 18.5 cm) over consecutive nights was 13,002 over 10 nights. The percentage of colonies planulating peaked on lunar day 10 (Fig. 2); between 25% and 87.5% of colonies planulated during the period of planulation.

Pocillopora damicornis

Planulation in this species also showed an apparent lunar pattern; planulae were released from lunar days 2 to 9 with the peak numbers of planulae released and planulating colonies both occurring on lunar day 6 (Figs. 1, 2). The mean lunar day of planula release was 5.7 with an angular deviation of 28.0; the clustering of planulae around this day was very significant (Table 1).

The maximum number of larvae released by a single colony (mean diameter, 7.3 cm) on 1 night was 76, with this colony releasing a total of 213 larvae over 6 nights. The percentage of the colonies planulating varied from 25% to 62.5% during the period of planulation.

Stylophora pistillata

Planulation in this species occurred throughout the month (Figs. 1, 2). However, the numbers of planulae released and colonies planulated peaked on lunar days 21 and 22. The mean lunar day of planula release was 24.5 with an angular deviation of 68.5; the clustering of planulae around this day was significant (Table 1). The maximum number of larvae released by a single colony (mean diameter, 19.0 cm) on 1 night was 195. This colony released a total of 1093 larvae over 20 nights. The percentage of colonies planulating ranged from 12.5% to 87.5% during the period of planulation.

Larval size

Maximum mean larval diameter was 954 ± 28 μm (Mean ± 1 SD, *n* = 20) for *Seriatopora hystrix* on lunar day 7; 1442 ± 27 μm (*n* = 20) for *Pocillopora damicornis* on lunar day 7; and 1310 ± 65 μm (*n* = 7) for *Stylophora pistillata* on lunar day 20.

Larval settlement

No planula of *Seriatopora hystrix* settled within 24 h during the period from 30 December to 2 January; this was significantly lower than a mean of 2.6 planulae settling on petri dishes from 3 to 9 January (Fig. 3; $F = 5.4$, $p < 0.05$). There was a

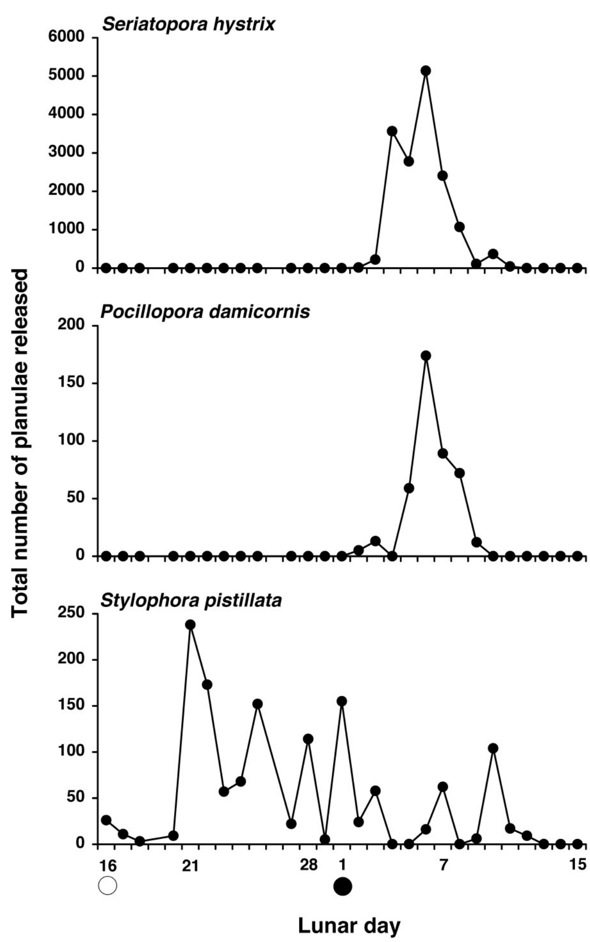

Fig. 1. Total number of planulae released per day from colonies of 3 pocilloporid species kept in aquaria from 20 April (lunar day 16) to 18 May (lunar day 15) 2000.

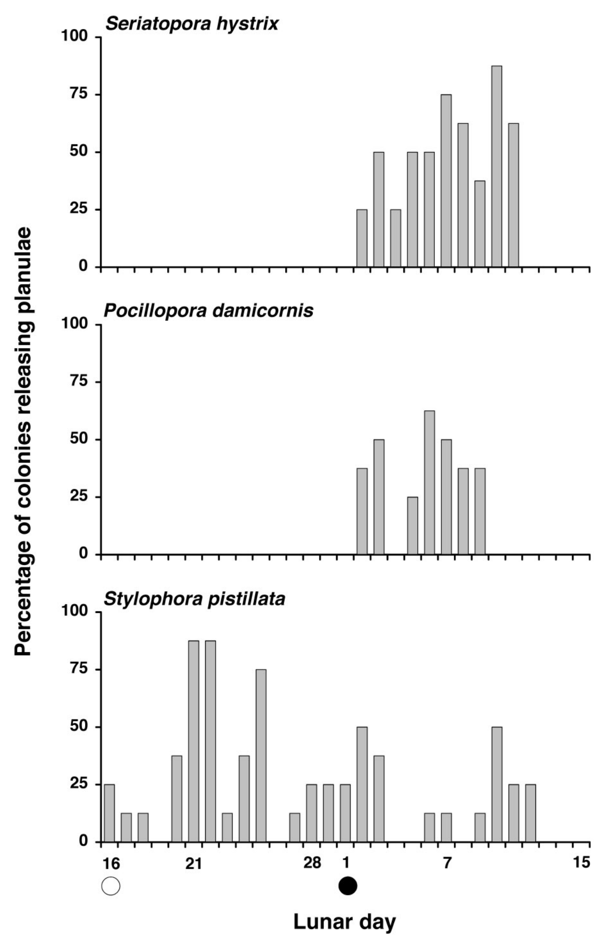

Fig. 2. Percentage of planulating colonies per day in 3 pocilloporid species kept in aquaria from 20 April (lunar day 16) to 18 May (lunar day 15) 2000.

significant difference between the mean of 1.6, 4.4, and 7.2 planulae of *Stylophora pistillata* settling from 30 December to 4 January, from 5 to 8 January, and 9 to 10 January, respectively (Fig. 3; $F = 28.4$, $p < 0.001$). Over the 12-d experimental period, no planula of *Pocillopora damicornis* settled in petri dishes. This suggests that larvae released later had a higher proportion of settlement within 24 h for *S. hystrix* and *S. pistillata*.

DISCUSSION

This study investigated the timing of planulation and the number of larvae released by 3 common pocilloporid species in southern Taiwan. Planulation of *Seriatopora hystrix* and *Pocillopora damicornis* revealed a well-defined lunar pattern in which planulae were released during the new moon and 1st quarter. Planulation of *Stylophora pistillata* occurred throughout the lunar phase, but more planulae were released in the 2nd-quarter moon phase.

Reproductive cycles of the 3 pocilloporid corals in southern Taiwan were studied by histological examination and planulae collection in the field using planktonic nets which indicated that development of gametes and larvae, and planulation of these species occurred in almost every month throughout the year (Dai et al. 1992, Fan and Dai 1996, unpubl. data). These field data showed that planulae of the 3 pocilloporid species can be captured during all 4 lunar phases with higher collections during the new moon and 1st quarter for *S. hystrix* (Fan and Dai 1996) and *P. damicornis* (Fan and Dai unpubl. data). Planulation by the 3 coral species in the present study showed trends similar to those observed in previous studies (Fan and Dai 1996, unpubl. data), although the period of planulation might be longer when using planktonic nets to collect larvae in the field.

Lunar cycles of planulation have been recorded in many brooding corals and may vary among allopatric populations of the same species (Harrison and Wallace 1990, Richmond and Hunter 1990, Tanner 1996). Planulation of *Seriatopora hystrix* in southern Taiwan is similar to that in Palau, Enewetak, and Heron Island in the southern Great Barrier Reef with more planulae released during the new and 1st-quarter moon phases (Atoda 1951, Stimson 1978, Tanner 1996).

The lunar pattern of planulation in *Pocillopora damicornis* in southern Taiwan shows similar periodicity to that at Enewetak (Richmond and Jokiel 1984), but differs from those in southwestern Japan (Tioho et al. 2001), Heron Island (Tanner 1996), and southern Western Australia (Stoddart and Black 1985) where planula production peaks during the 2nd-quarter moon phase.

Similar to that in southern Taiwan, planulation by *Stylophora pistillata* at Heron Island (Tanner 1996) and in the Red Sea (Rinkevich and Loya 1979) occurs throughout the lunar phases. In contrast, planulation by *S. pistillata* in Palau occurs between the full and new moons (Atoda 1947b).

The period in which planulae were released by the 3 pocilloporid coral species in this study is consistent with the appearance of mature larvae in the coelenteron of their parent polyps from histo-

Table 1. Test for uniformity of lunar distribution of the release of planulae by 3 pocilloporid species. z is the test statistic (Rayleigh's Test, Zar 1984), and n is the number of colonies releasing planulae

	Seriatopora hystrix	*Pocillopora damicornis*	*Stylophora pistillata*
Mean lunar day	7.2	5.7	24.5
Angular deviation	32.8	28.0	68.5
z	29.4	18.6	3.4
n	42	24	58
Probability of a uniform distribution	$p < 0.001$	$p < 0.001$	$0.02 < p < 0.05$

logical examination (Fan and Dai 1996, unpubl. data). Thus, the most probable explanation for the lunar periodicity in planulation for the 3 coral species is that it is an effect of the lunar cycle on the development of gametogenesis and embryogenesis. It has been suggested that the periodicity in larval release is a result of earlier periodicity in the release of mature sperm and of a fixed maturation time for larvae (Szmant-Froelich et al. 1985, Kojis 1986). However, the long planulation by *Stylophora pistillata* may be due to planulae residing in the polyps longer, thus extending the length of larval release (Tanner 1996).

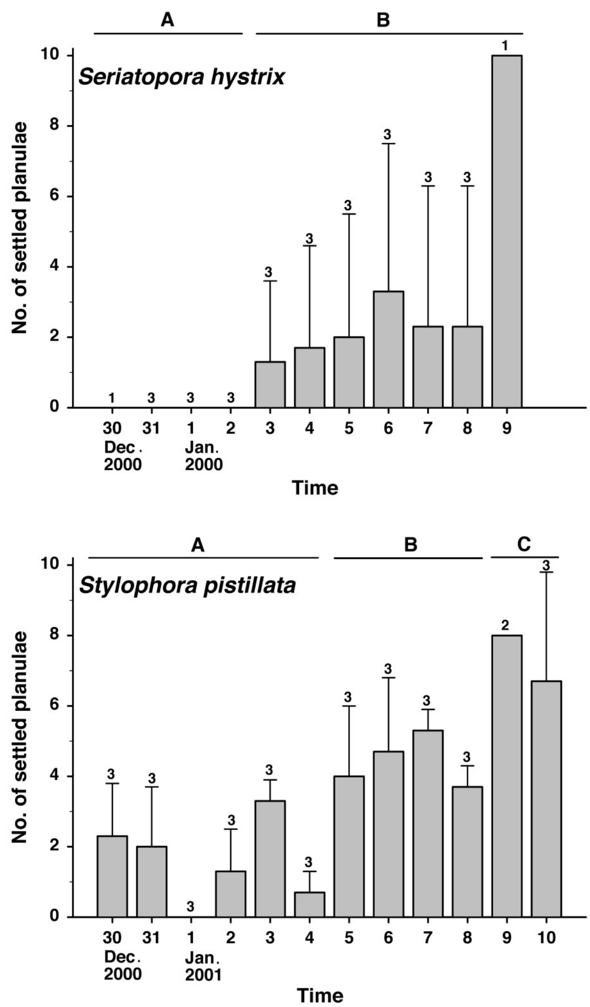

Fig. 3. Mean number of planulae settling on plastic petri dishes within 24 h each day by *Seriatopora hystrix* and *Stylophora pistillata* from 30 December 2000 to 10 January 2001. Horizontal bars indicate results of one-way ANOVA; means with different letters significantly differ ($p < 0.05$). Numbers above bars indicate the number of repetitions. Error bars = 1 SD.

The settlement period of larvae of the 3 coral species in this study is similar to that of most brooded planulae which settle quickly, usually within 1 or a few days after being released from their parent polyp (Harrison and Wallace 1990). This study also revealed that a higher proportion of larvae released later seemed to settle faster than those released earlier. Variations in settlement times following planulation appear to result from differences in the developmental stage at which a planula was released and may have important implications for the dispersal potential of coral planulae (Harrison and Wallace 1990).

Knowledge of reproductive patterns and settling preferences of coral species can lead to an assessment of the potential use of their propagules to restore degraded coral reefs. It has been suggested that fast-growing brooding coral species such as the pocilloporid corals in this study are the best candidates for restoration of coral reefs by employing sexual recruits (Rinkevich 1995). Based on the reproduction and settlement information available from this study, it would be practical to obtain a large number of competent planulae, seed them on suitable substrata, and then transfer them to reefs for restoring damaged coral populations and communities in coral reefs (Oren and Benayahu 1997).

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臺灣南部三種鹿角珊瑚釋放幼生的月週期

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本研究利用戶外流水式水箱收集幼生的方法，探討臺灣南部三種孵育幼生型珊瑚，即尖枝列孔珊瑚、細枝鹿角珊瑚和萼形柱珊瑚釋放幼生的月週期。尖枝列孔珊瑚和細枝鹿角珊瑚在新月至上弦月期間釋放幼生，呈現明顯的月週期；而萼形柱珊瑚在各月週期期間都有釋放幼生，但以下弦月期間釋放的幼生數量較多。三種鹿角珊瑚釋放幼生的月週期時間，可能與其配子和胚胎發育的月週期有關。對尖枝列孔珊瑚和萼形柱珊瑚而言，較晚釋出的幼生，其於24小時內在塑膠培養皿表面的附著率較高。未來將可利用這些珊瑚的生殖和幼生行為特性，取得大量成熟幼生，使其附著於適當基質並成長為群體後，再移植至被破壞礁區，進行珊瑚群聚重建的復育工作。

關鍵詞：珊瑚，幼生釋放，月週期，附著。

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